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for
TESTING MATERIALS

PROCEEDINGS
of the
FORTY-SECOND ANNUAL MEETING

Held at Atlantic City, N. J.

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TECHNICAL PAPERS

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SUMMARY OF PROCEEDINGS OF THE FORTY-SECOND ANNUAL MEETING

ATLANTIC CITY, N. J., JUNE 26–30, 1939

The following Summary records the action taken by the Society at the Annual Meeting on the Recommendations Affecting Standards and Tentative Standards appearing in the annual reports of the standing committees. In the individual committee reports attention is called through an editorial footnote to any modifications of the recommendations or where the recommendations of the committee were not approved. In all other instances it is to be understood that the recommendations were approved as submitted by the committee. The new and revised standards and tentative standards are published in the 1939 Book of A.S.T.M. Standards, Parts I, II, and III. Except as noted, the reports and papers appear in this volume.

This summary of the Forty-second Annual Meeting of the American Society for Testing Materials, held at Chalfonte-Haddon Hall, Atlantic City, N. J., June 26–30, 1939, is a record of the transactions of the meeting including the actions taken on the various recommendations submitted by the standing committees. In all, 22 sessions were held,—18 formal sessions and four round-table discussions—as well as the Fifth Exhibit of Testing Apparatus and Related Equipment, the Second A.S.T.M. Photographic Exhibition and Competition, and the Twenty-second Annual A.S.T.M. Golf Tournament. The exhibit of testing apparatus and the photographic exhibition are described in some detail in the August ASTM BULLETIN.

The *Proceedings* are set forth session by session. There were 62 reports and 60 formal papers presented. The record with respect to each has been briefed, the recommendations in the reports having been grouped so as to cover the acceptance of material for publication as tentative, such as new specifications, methods of test, revisions of tentative standards and proposed revisions of existing standards, and as a separate group, the approval of matters that were referred to letter ballot of the Society, as for example, the adoption of tentative standards as standard or the adoption of revisions of standards. Accordingly, wherever the action is reported as "adopted as standard," it is understood that this indicates approval of the annual meeting for reference to letter ballot of the Society. The various recommendations so recorded are included in the Society letter ballot.[1] The actions designated as "accepted as tentative" are self evident as indicating acceptance by the Society at the annual meeting for publication as tentative.

While all of the items on the program are recorded under the particular session in which they were presented, for convenience in locating actions with respect to any particular report, the accompanying list is presented of all the reports together with the page reference where the action thereon is recorded.

The registered attendance of the meeting is as follows: Members present or represented, 921; committee members, 202; guests, 231; total, 1354; ladies, 309.

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[1] The letter ballot on recommendations affecting standards, distributed to the Society membership, was canvassed on September 15, 1939, and all actions were approved.

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FORMAL OPENING SESSION
PRESIDENT'S ADDRESS

Tuesday, June 27, 10.30 a.m.

Session Co-Chairmen: President T. G. Delbridge; Past-President H. S. Vassar.

President Delbridge in opening the Forty-second Annual Meeting stated that from the attendance records, the number of scheduled meetings and technical sessions, the fine exhibit of testing apparatus, and other scheduled activities, this meeting promised to be the most successful that the Society has yet held. In referring to the accomplishments of the Society during the past year, he pointed out that they were made possible only through the constant cooperation of the members of the standing committees. President Delbridge stressed the importance of the service which the Society is rendering to industry and the significance attached to its work in the field of engineering materials in advancing scientific progress.

Committee E-9 on Research:

Report presented from manuscript by T. S. Fuller, chairman.

Committee E-10 on Standards:

Report presented from manuscript by Cloyd M. Chapman, chairman.

Executive Committee:

This report, which discussed Society activities, covered membership, publication, finances, and administrative matters relating to committee activities and inter-Society relations, was presented by the Secretary-Treasurer, C. L. Warwick. The report recommended revisions of the By-laws, which revisions were approved for reference to letter ballot, as follows:

Revisions of By-laws:

Article II. Officers and Their Election, revision of Section 3
Article IV. Duties of Officers, revision of Section 2
Article V. Meetings, revision of Section 1
New Article VI. Administrative and Other Committees
Article VI (Renumbered Article VII). Procedure Governing the Adoption of Standards, revision of Section 1

Past-President H. S. Vassar then assumed the chair.

The chairman presented the President, T. G. Delbridge, who delivered the annual Presidential Address on "Glimpses at Petroleum" in which he presented a brief historical review of this natural mineral product and the part it has played as an important engineering material and the basis of a mighty industry. He referred to the many problems that the discovery, production, transportation, use, and development of petroleum had presented to the explorer, driller, chemist, engineer, banker, and merchant. President Delbridge emphasizes that while the petroleum industry has made some important contributions to the work of the Society, the A.S.T.M. has contributed greatly to the industry in that it has been the forum in which petroleum men as producers could discuss broad and specific problems with consumers, and the medium through which it has been possible to coordinate research work and to standardize specifications and many test methods for petroleum and its products.

The chairman announced that in accordance with action taken by the Executive Committee, certificates were being awarded to four individuals and companies who had attained forty years of membership in the Society, as follows:

W. H. Broadhurst, Chemist, Bureau of Highways, Brooklyn, N. Y.
F. G. Kennedy, Jr., President, Logan Iron and Steel Co., Philadelphia, Pa.

Robert W. Hunt Co., Chicago, Ill.
The Lowe Brothers Co., Dayton, Ohio.

The chairman then recognized C. S. Reeve, chairman of the Committee of Tellers, who reported the results of the letter ballot on election of officers. Of the 1055 ballots cast, the results were as follows:

For President, to serve for one year:
  H. H. Morgan, 1050 votes.
For Vice-President, to serve for two years:
  G. E. F. Lundell, 1050 votes.
For Members of the Executive Committee, to serve for two years:
  J. J. Allen, 1033 votes.
  R. D. Bonney, 1039 votes.
  T. S. Fuller, 1032 votes.
  J. L. McCloud, 1037 votes.
  M. A. Swayze, 1035 votes.

The chairman then introduced the newly elected members of the Executive Committee, requesting that they rise and remain standing, as their names were called.

At the request of the chairman, Past-President A. C. Fieldner escorted to the chair the Vice-President-Elect, G. E. F. Lundell, who, in expressing appreciation of the honor bestowed upon him in his election, pledged his best efforts to work with the officers and uphold the traditions of the Society.

The chairman then requested Past-President H. F. Moore to escort to the chair the President-Elect, H. H. Morgan, who in acknowledging the honor of his election, stated that he would continue to give his most earnest and consistent attention to the fundamental interests and general interests of the Society.

SECOND SESSION—PAINT AND RELATED PRODUCTS

Tuesday, June 27, 2 p.m.

Session Co-Chairmen: C. D. Holley; G. G. Sward.

Committee D-1 on Paint, Varnish, Lacquer, and Related Products:

Report presented by M. Rea Paul, secretary, and the following actions taken:

Accepted as Tentative:

- Spec. for Shellac Varnishes, to replace Standard Specs. D 359 and D 360
- Spec. for Zinc Dust (Metallic Zinc Powder)
- Chemical Analysis of Zinc Dust (Metallic Zinc Powder)
- Test for Specular Gloss of Paint Finishes
- Test for Elongation of Attached Lacquer Coatings with the Conical Mandrel Test Apparatus.
- Revisions of:
  - Spec. for Orange Shellac (D 237 - 33)
  - Spec. for Butanol (Normal Butyl Alcohol) (D 304 - 33)
  - Spec. for Amyl Alcohol (Synthetic) (D 319 - 33)
  - Routine Analysis of White Linseed Oil Paints (D 215 - 37)
  - Sampling and Testing Lacquer Solvents and Diluents (D 268 - 33)

Adopted as Standard:

- Spec. for Petroleum Spirits (Mineral Spirits) (D 235 - 34 T)
- Spec. for Aluminum Pigment Paste for Paint (D 474 - 38 T)
- Spec. for C. P. Para Red Toner (D 475 - 38 T)
- Spec. for Zinc Sulfide Pigments (D 477 - 38 T)
- Spec. for C. P. Zinc Yellow (Zinc Chromate) (D 478 - 38 T)
- Spec. for Titanium Dioxide Pigments (D 476 - 38 T), as revised
- Routine Analysis of Zinc Yellow Pigment (Zinc Chromate Yellow) (D 444 - 38 T), as revised
- Analysis for Spectral Apparent Reflectivity of Paints (D 307 - 37 T), as revised
- Test for Soluble Nitrocellulose Base Solutions (D 365 - 35 T)
- Test for Relative Dry Hiding Power of Paints (D 344 - 37 T); this recommendation not having been preprinted, was approved by unanimous consent, subject to favorable letter ballot of Committee D-1,[2] with the following revision:

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[2] Committee D-1 reported the following results of the letter ballot vote of a total of 122 ballots returned from a voting membership of 224: D 344, affirmative 90, negative 0; D 406, affirmative 97, negative 1; D 153, affirmative 87, negative 0; D 186, affirmative 90, negative 0.

Section 3 (*e*).—In the second and third sentences, change "diffuse reflection" to "diffuse reflectance."

Test for Relative Dry Hiding Power of White Pigments (D 406 – 37 T); this recommendation not having been preprinted, was approved by unanimous consent, subject to favorable letter ballot of Committee D-1,[2] with the following revisions:

Title.—Add the following words to the title: "in a Linseed Oil Vehicle."

Section 1.—In the first sentence add after "white pigment" the words "in a linseed oil vehicle."

Section 3 (*e*).—In the second and third sentences, change "diffuse reflection" to "diffuse reflectance."

Revisions of:

Spec. for Red Lead (D 83 – 31)

Spec. for Commercial Para Red (D 264 – 28)

Spec. for Aluminum Powder for Paints (Aluminum Bronze Powder) (D 266 – 31)

Sampling and Testing Shellac (D 29 – 33)

Routine Analysis of Dry Cuprous Oxide (D 283 – 36)

Spec. for Zinc Oxide (D 79 – 24)

Spec. for Prussian Blue (D 261 – 28)

Spec. for Normal Amyl Acetate (D 318 – 36)

Routine Analysis of White Pigments (D 34 – 33)

Revision of Test for Specific Gravity of Pigments (D 153 – 27); this recommendation not having been preprinted, was approved by unanimous consent, subject to favorable letter ballot of Committee D-1,[2] as follows:

Section 13 (*b*).—Change the second sentence to read as follows by the addition of the italicized material and the omission of that in brackets:

The flask shall be thick enough to withstand and maintain a vacuum and should weigh *between 50 and 60 g.* [less than 35 g.]

Revision of Routine Analysis of Titanium Pigments (D 186 – 33); this recommendation not having been preprinted, was approved by unanimous consent, subject to favorable letter ballot of Committee D-1,[2] as follows:

Section 9.—Second paragraph, change to read as follows by the addition of the italicized material and the omission of that in brackets:

Dilute the filtrate to 200 cc. and add about *5 ml.* [10 cc.] of NH_4OH (sp. gr. 0.90) to lower the acidity to approximately *10 to 15* [5] per cent H_2SO_4 (by volume).

Section 9.—Change items (*1*) and (*2*) to read as follows by the addition of the italicized material and the omission of that in brackets:

(*1*) Run 50 cc. of the 5 per cent H_2SO_4 solution through the reductor *at such a uniform rate as to require 5 to 10 min. for passage* [at a speed of about 100 cc. per minute].

(*2*) Follow this with the titanium solution *at such a uniform rate as to require 10 min. to pass through the reductor.*

Withdrawal of Standards and Tentative Standards:

Spec. for Shellac Varnish (D 359 – 35)

Spec. for Centrifuged Shellac Varnish (D 360 – 34)

Spec. for Lithopone (D 208 – 26)

Spec. for Titanium Barium Pigment (D 382 – 35)

Spec. for Titanium Calcium Pigment (D 383 – 35)

Spec. for Titanium Dioxide (D 384 – 36)

Spec. for Zinc Sulfide – Barium Pigment (D 385 – 36)

Spec. for Zinc Sulfide (D 386 – 36)

Spec. for Titanium Magnesium Pigment (D 442 – 37 T)

Spec. for Zinc Sulfide Magnesium Pigment (D 443 – 37 T)

Symposium on Paint Testing:

Mr. Sward in introducing the Symposium on Paint Testing, stated that it had been sponsored by Committee D-1 on Paint, Varnish, Lacquer, and Related Products, for the purpose of making available information concerning tests developed within recent years, some of which were already embodied in A.S.T.M. Standards for the evaluation of paints and paint materials. The chairman pointed out that Committee D-1 maintains a very real interest in the promotion of knowledge of those materials under its jurisdiction by the preparation of testing methods and specifications, the conducting of cooperative studies on materials and test procedures, and in arranging for the presentation of technical papers describing new and interesting developments.

The following eleven papers comprising the Symposium,[3] dealing with miscellaneous tests or testing devices for evaluating finishing materials, were then presented by the authors, except as indicated:

The Aeration Test for Comparison of Thinners—D. D. Rubek.

The Krebs-Stormer Viscometer—Roscoe H. Sawyer.

Texture of Paints and Enamels—E. W. Fasig.

Testing of Rust-Inhibitive Paints by the Cook-Box Method—E. W. McMullen.

Detective Work on Metal Finishes—V. M. Darsey, presented by F. J. DeWitt, Jr.

The Conical Mandrel for Measuring Elongation of Attached Films—H. G. Arlt; the subject covered by this paper was illustrated by motion pictures.

Elasticity and Hardness of House Paints—W. H. Hoback.

An Apparatus for Determining the Durability of Heat-Resisting Paints—G. W. Ashman and S. Werthan, presented by Mr. Ashman.

Some Fundamental Requirements of Colorimeters and Reflectometers—Richard S. Hunter.

Presentation of Color—Francis Scofield.

Sheen Meter—J. W. Ayres, presented by C. J. Love.

THIRD SESSION—IRON

Tuesday, June 27, 2 p.m.

Session Chairman: J. J. Shuman.

Committee A-2 on Wrought Iron:

Report presented by C. B. Bryant, chairman, and the following actions taken:

Accepted as Tentative:

Revision of Spec. for Single and Double Refined Wrought-Iron Bars (A 189 - 37 T)

The recommendation in the report as preprinted for the adoption as standard of Specifications A 189, as revised, was withdrawn.

Adopted as Standard:

Spec. for Wrought-Iron Plates (A 42 - 37 T)

Spec. for Wrought-Iron Rivets and Rivet Rounds (A 152 - 37 T)

Spec. for Rolled Wrought-Iron Shapes and Bars (A 207 - 38 T)

Revisions of:

- Spec. for Iron and Steel Chain (A 56 - 30)
- Spec. for Welded Wrought-Iron Pipe (A 72 - 38)
- Spec. for Staybolt Wrought Iron, Solid (A 84 - 36)
- Spec. for Staybolt Wrought Iron, Hollow Rolled (A 86 - 36)
- Spec. for Uncoated Wrought-Iron Sheets (A 162 - 36)
- Spec. for Zinc-Coated (Galvanized) Wrought-Iron Sheets (A 163 - 36)
- Spec. for Wrought-Iron Rolled or Forged Blooms and Forgings (A 73 - 36)

The Tentative Specifications for Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 - 38 T) were recommended by Committee A-2 for adoption as standard subject to similar action by Committee A-1 on Steel since these specifications are under the joint jurisdiction of these committees.

Sectional Committee A21 on Specifications for Cast-Iron Pipe and Fittings:

Oral progress report presented by T. H. Wiggin, chairman.

The chairman announced that the sectional committee had completed the preparation of Specifications for Cast-Iron Pit-Cast Pipe for Water or Other Liquids, and for Cement Mortar Lining for Cast-Iron Pipe and Fittings. These specifications were being referred to Committee A-3 on Cast Iron for consideration for submission to the Society through Committee E-10 on Standards for publication as A.S.T.M. tentative standards. They have been approved by the sectional committee for submission to the American Standards Association for approval as American Standard, and action on this submittal by the Society will be taken in due course.

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[3] Published in ASTM BULLETIN, No. 102, January, 1940.

Committee A-3 on Cast Iron:

Report presented by W. H. Rother, chairman, and the following action taken:

Withdrawal of Standard:

Spec. for the Arbitration Test Bar and Tension Test Specimen for Cast Iron (A 124 – 29)

Committee A-7 on Malleable-Iron Castings:

Report presented by E. K. Smith, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Pearlitic Malleable Iron Castings

Adopted as Standard:

Spec. for Cupola Malleable Iron (A 197 – 36 T)

Papers:

The following papers were presented:

Mechanical Properties of a High-Strength Cast Iron—Jasper O. Draffin and W. L. Collins, presented by Mr. Collins.

Influence of Chromium on the Oxidation Resistance of Cast Iron—C. O. Burgess, presented by the author.

The Resistance of High-Silicon Malleable Iron to Drilling—H. A. Schwartz, R. C. Kasper and N. E. Mertz, presented by C. H. Junge.

The Relation of Carbon Nodule Size and Tensile Properties of Malleable Cast Iron—H. A. Schwartz, H. J. Schindler and J. F. Elliott, presented by C. H. Junge.

FOURTH SESSION—WATER

Tuesday, June 27, 8 p.m.

Session Co-Chairmen: Vice-President W. M. Barr; E. P. Partridge.

Committee D-19 on Water for Industrial Uses:

Report presented by Max Hecht, chairman.

Joint Research Committee on Boiler Feedwater Studies:

Report[4] presented from manuscript by J. B. Romer, secretary.

Papers:

The following papers were presented:

The Calculation of Equilibria in Dilute Water Solutions—D. S. McKinney, presented by the author.

The Calculation of the Distribution of Carbon Dioxide Between Water and Steam—A. M. Amorosi and J. R. McDermet, presented by Mr. Amorosi.

Determination by the Evaporation Method of Small Amounts of Dissolved Solids in Water Such as Condensed Steam from Boilers—R. C. Ulmer, presented by the author.

Electrical Conductance Measurements of Water Extracts of Textiles—A. C. Walker, presented from manuscript by the author.

The pH, Dissolved Iron Concentration and Solid Product Resulting from the Reaction Between Iron and Pure Water at Room Temperature—Richard C. Corey and Thomas J. Finnegan, presented by Mr. Finnegan.

ROUND-TABLE DISCUSSION ON EFFECT OF SUB-ATMOSPHERIC TEMPERATURES ON THE PROPERTIES OF METALS

Tuesday, June 27, 8 p.m.

Session Co-Chairmen: N. L. Mochel; F. B. Foley.

The Discussion on Effect of Sub-Atmospheric Temperatures on the Properties of Metals was sponsored by the Joint High Temperature Committee in view of the increasing demand for metals having properties which make them suitable for use at sub-atmospheric temperatures. While there is a considerable amount of information extant bearing on the behavior of metals at low temperatures, there is a need and a demand for gathering together all the available knowledge possible on the subject in a form in which it will be available to engineers and metallurgists. With this in view, in addition to three formal papers dealing with certain phases of impact testing at low temperatures, the round-table discussion was introduced as follows:

Steel for Low-Temperature Service—F. B. Foley.

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[4] Published in ASTM Bulletin, No. 99, August, 1939, p. 52.

Aircraft Metals Subject to Sub-Atmospheric Temperatures—H. J. Huester.
Non-Ferrous Metals for Low-Temperature Service—B. B. Morton.

The discussion of the meeting will be summarized by F. B. Foley for publication in the A.S.T.M. *Proceedings.*

The three formal papers which were presented with the Round-Table Discussion were the following, which papers will appear with the other technical papers in the *Proceedings:*

Mechanical Properties of Copper and its Alloys at Low Temperatures: A Review—Cyril Stanley Smith.
Sub-Size Charpy Relationships at Sub-Zero Temperatures—H. Habart and W. J. Herge, presented by Mr. Habart.
Factors Affecting Notched-Bar Impact Tests on Steel at Low Temperatures—Walter Crafts and John J. Egan, presented by Mr. Egan.

FIFTH SESSION—PAPER, PLASTICS, RUBBER, GLASS, ELECTRICAL INSULATING MATERIALS

Wednesday, June 28, 9.30 a.m.

Session Chairman: Dean Harvey.

Committee D-6 on Paper and Paper Products:

Report presented by R. C. Griffin, chairman, and the following actions taken:

Accepted as Tentative:

Test for Machine Direction of Paper
Test for Bulking Thickness of Paper; not having been preprinted, it was accepted by unanimous consent, subject to favorable letter ballot of Committee D-6.[5]

The proposed new Tentative Method of Test for Paraffin Content of Paper and Paper Products was withdrawn from the report by the committee.

Committee D-20 on Plastics:

Report presented by W. E. Emley, chairman, and the following actions taken:

Accepted as Tentative:

Test for Index of Refraction of Transparent Organic Plastics
Test for Resistance of Plastics to Chemical Reagents

Committee D-11 on Rubber Products:

Report presented by O. M. Hayden, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Rubber Sheath Compound for Electric Cords and Cables
Testing Hard Rubber Products
Test for Indentation of Rubber by Means of the Pusey and Jones Plastometer
Revisions of:
  Testing Flat Rubber Belting (D 378 - 38 T)
  Testing Rubber Hose (D 380 - 38 T)
  Tension Testing of Vulcanized Rubber (D 412 - 36 T)
  Testing Rubber Insulated Wire and Cable (D 470 - 38 T)
  Spec. for Insulated Wire and Cable: Class AO, 30 per cent Hevea Rubber Compound (D 27 - 38 T)
  Spec. for Insulated Wire and Cable: Performance Rubber Compound (D 353 - 37 T)
  Spec. for Insulated Wire and Cable: Heat-Resisting Rubber Compound (D 469 - 37 T)

The revisions in the latter three specifications were accepted with the exception of the proposed changes in Table V of D 27 and in Table II of D 353 and D 469 which were withdrawn by the committee.

Adopted as Standard:

Sample Preparation for Physical Testing of Rubber Products (D 15 - 38 T)
Test for Adhesion of Vulcanized Rubber (Friction Test) (D 413 - 36 T)
Test for Adhesion of Vulcanized Rubber to Metal (D 429 - 36 T)
Revision of Test for Hardness of Rubber (D 314 - 34)
Revision of Chemical Analysis of Rubber Products (D 297 - 38)

Withdrawal of Tentative Standard:

Spec. for Rubber Pump Valves (D 151 - 31 T)

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[5] Committee D-6 reported results of the letter ballot vote as follows: Of a total voting membership of 46, 28 members returned their ballots, of whom 25 voted affirmatively, 0 negatively.

Committee C-14 on Glass and Glass Products:

Brief progress report, in absence of chairman, presented by the Secretary-Treasurer.

Committee D-9 on Electrical Insulating Materials:

Report presented by T. Smith Taylor, chairman, and the following actions taken:

Accepted as Tentative:

Revisions of:
- Test for Dielectric Strength of Insulating Materials, at Commercial Power Frequencies (D 149 - 38 T)
- Spec. for Black Bias-Cut Varnished Cloth Tape Used for Electrical Insulation (D 373 - 37 T)
- Testing Pin-Type, Lime Glass Insulators (D 468 - 38 T)
- Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - —)
- Testing Laminated Tubes Used in Electrical Insulation (D 348 - —)
- Testing Laminated Round Rods Used in Electrical Insulation (D 349 - —)

The tentative revision in Methods D 229, D 348 and D 349 were accepted with the addition of the following notes:

NOTE 1.—Conditioning of specimens may be undertaken: (*a*) for the purpose of bringing the material into equilibrium with standard normal conditions, 25 C. and 40 per cent relative humidity; (*b*) simply to obtain reproducible results, irrespective of previous history of exposure; or (*c*) to subject the material to abnormal conditions of temperature or humidity in order to predict its service behavior.

The conditions given here to obtain reproducible results may give physical values somewhat higher or somewhat lower than values under equilibrium at normal conditions, depending upon the particular material and test. To insure substantial equilibrium under normal conditions of humidity and temperature, however, will require from 20 to 100 days or more depending upon thickness and type of material and its previous history. Consequently, conditioning for reproducibility must of necessity be used for general purchase specification and product control tests.

NOTE 2.—Conditioning of specimens for electrical tests is also necessary to obtain consistent results. The procedure for such conditioning is under consideration by the committee. In order to secure comparative results, specimens should be conditioned at the same temperature and humidity.

Adopted as Standard:

- Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 38 T)
- Testing Laminated Tubes Used in Electrical Insulation (D 348 - 38 T)
- Testing Laminated Round Rods Used in Electrical Insulation (D 349 - 35 T), as revised
- Revision of Testing Molded Materials Used for Electrical Insulation (D 48 - 37)
- Revision of Testing Electrical Porcelain (D 116 - 34); this recommendation for adoption of the tentative revision[6] not having been preprinted, was approved by unanimous consent, subject to favorable letter ballot of Committee D-9[7]
- Revision of Testing Pasted Mica Used in Electrical Insulation (D 352 - 36); this recommendation for adoption of the tentative revision[6] and the addition to the methods of an Appendix giving requirements for cells for low power-factor liquids not having been preprinted was accepted by unanimous consent, subject to favorable letter ballot of Committee D-9[7]

Papers:

The following papers were presented:

Properties of Rubber Revealed by Mechanical Tests[8]—Felix L. Yerzley, presented by the author.

A New Mechanical Oscillograph for Routine Tests of Rubber and Rubber-Like Materials—Felix L. Yerzley, presented by the author.

Burst Test Data on Laminated Glass[9]—W. R. Koch and E. J. Wyrostek, presented from manuscript by Mr. Koch; the subject covered by the paper was illustrated by motion pictures.

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[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1337, 1338 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1703, 1704.

[7] Committee D-9 reported results of the letter ballot vote as follows: Of a total voting membership of 92, 31 members returned their ballots, all of whom voted affirmatively.

[8] Published in ASTM BULLETIN, No. 99, August, 1939, p. 31.

[9] Published in ASTM BULLETIN, No. 103, March, 1940.

SIXTH SESSION—FATIGUE, CORROSION

Wednesday, June 28, 9.30 a.m.

Session Co-Chairmen: T. S. Fuller; F. F. Farnsworth.

Research Committee on Fatigue of Metals:

Report presented by H. F. Moore, chairman.

Report of Committee A-5 on Corrosion of Iron and Steel:

Report presented by W. H. Finkeldey, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Zinc-Coated Steel Wire Strand (Class B and Class C Coatings), revised as follows:

Section 6.—Change from the form as preprinted: namely,

6. Strand shall be preformed when specified by the purchaser. The preforming operation consists of permanently shaping the component wires to the helical form they assume in the finished strand prior to the fabrication of the strand.

to read as follows:

6. Preformed strand shall be supplied when so specified by the purchaser. Strand is preformed when the component wires are set to the helical form that they assume in the product by any means or process other than by merely laying them about the strand core.

Section 18.—Change the last sentence from the form as preprinted to read as follows by the addition of the italicized words and the omission of the word in brackets:

Each coil or reel shall have a strong tag securely fastened to it showing the length, size, [and] grade of the strand, *class of coating*, and the name or mark of the manufacturer.

Methods of Test for Local Thickness of Electrodeposited Coatings on Steel

Revisions of:

- Spec. for Electrodeposited Coatings of Zinc on Steel (A 164 – 35 T)
- Spec. for Electrodeposited Coatings of Cadmium on Steel (A 165 – 35 T)
- Spec. for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 – 35 T)

Revision of Spec. for Zinc-Coated (Galvanized) Iron or Steel Wire Strand (Cable) (A 122 – 33), with additional changes identical with those listed above for the Spec. for Zinc-Coated Steel Wire Strand.

Adopted as Standard:

Spec. for Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (A 116 – 37 T)

Spec. for Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 – 37 T)

Revision of Methods of Determining Weight and Uniformity of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 – 33)

Withdrawal of Standard:

Methods of Determining Weight of Coating on Tin, Terne and Lead-Coated Sheets (A 91 – 24)

The recommendation for the adoption as standard of the Tent. Spec. for Zinc-Coated (Galvanized) Iron or Steel Sheets (A 93 – 38 T) was withdrawn from the report by the committee.

Mr. Finkeldey then called upon C. D. Hocker to present the report of the Wire Inspection Committee on Field Tests of Wire and Wire Products.

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys:

Report presented by T. S. Fuller, chairman, and the following action taken:

Accepted as Tentative:

Salt Spray Testing of Non-Ferrous Metals

Mr. Fuller then called upon L. J. Gorman to present from manuscript the report of Subcommittee VIII on Galvanic and Electrolytic Corrosion.

The paper appended to the report on "Chemical Removal of Corrosion Products in the Determination of the Corrosion Rate of Zinc," by E. A. Anderson and C. E. Reinhard, was presented by Mr. Anderson.

Joint Committee on Exposure Tests of Plating on Non-Ferrous Metals:

Report presented from manuscript by William Blum, chairman.

Papers:

The following papers were presented:

Fatigue Tests of Wire[10]—C. P. Wampler and N. J. Alleman, presented by Mr. Alleman.

Fatigue Strength of Machined Forgings 6 to 7 in. in Diameter—O. J. Horger and H. R. Neifert, presented in abstract by H. F. Moore.

Fatigue Machines for Testing Structural Units—R. L. Templin, presented by the author.

Atmospheric Corrosion of Non-Ferrous Metals and Alloys—Carl W. Borgmann, presented by the author.

SEVENTH SESSION—SOAPS, TEXTILES, TIMBER

Wednesday, June 28, 2 p.m.

Session Chairman: President T. G. Delbridge.

Committee D-12 on Soaps and Other Detergents:

Report presented by the Chair, in absence of chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Sodium Metasilicate
Spec. for Trisodium Phosphate
Spec. for Palm Oil Bar Soap
Spec. for Palm Oil Chip Soap
Spec. for Built Soap, Powdered
Spec. for Soap Powder
Sampling and Chemical Analysis of Special Detergents (D 501 - 39 T)
Revision of Terms Relating to Soaps and Other Detergents (D 459 - 38 T), four revised and six new definitions

Adopted as Standard:

Revision of Spec. for Caustic Soda (D 456 - 38)
Revision of Spec. for Modified Soda (Sesquicarbonate Type) (D 457 - 38)
Spec. for Milled Toilet Soap (D 455 - 38 T)
Spec. for Soda Ash (D 458 - 38 T), as revised
Spec. for Chip Soap (D 496 - 38 T), as revised
Spec. for Ordinary Laundry Bar Soap (D 497 - 38 T), as revised
Spec. for Powdered Laundry Soap (D 498 - 38 T), as revised
Spec. for White Floating Toilet Soap (D 499 - 38 T)
Sampling and Chemical Analysis of Soaps and Soap Products (D 460 - 38 T), as revised
Chemical Analysis of Special Detergents (D 501 - 38 T)
Test for Particle Size of Soaps and Other Detergents (D 502 - 38 T)
Terms Relating to Soaps and Other Detergents (D 459 - 38 T), fourteen definitions

Committee D-13 on Textile Materials:

Report presented by H. J. Ball, chairman, and the following actions taken:

Accepted as Tentative:

Testing Rayon Staple
Testing and Tolerances for Single Jute Yarn
Test for Apparent Fluidity of Dispersions of Cellulose Fibers in Cuprammonium Hydroxide
Revisions of:
  Definitions and Terms Relating to Textile Materials (D 123 - 38 T)
  Testing and Tolerances for Rayon (D 258 - 37 T)
  Testing and Tolerances for Woven Tapes (D 259 - 36 T)
  Spec. and Tests for Asbestos Yarns (D 299 - 37)
  Spec. and Tests for Asbestos Roving for Electrical Purposes (D 375 - 37)
  Spec. and Tests for Cotton Goods for Rubber and Pyroxylin Coating (D 334 - 34)
Revision of Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 - 38); not having been preprinted, it was accepted by unanimous consent, subject to favorable letter ballot of Committee D-13,[11] as follows:

Section 11.—Change from its present form: namely,

11. (The committee is conducting a statistical study which, it is hoped, will permit the adoption of a proper formula for determining the number of tests required for all physical characteristics of tire cord.)

to read as follows:

11. The number of tests required for the determination of each physical property of tire cord shall be in accordance with Table I, which also gives the information on which the requirements are based. The sampling

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[10] Published in ASTM BULLETIN, No. 101, December, 1939, p. 13.

[11] Committee D-13 reported results of the letter ballot vote as follows: Of a total membership of 210, 93 members returned their ballots, of whom 44 voted affirmatively, 1 negatively.

of the shipment shall be as complete or representative as possible within practical limitations.

Adopted as Standard:

- Test for Shrinkage in Laundering of Silk and Rayon Woven Broad Goods (D 416 – 35 T) as revised
- Testing Pile Floor Coverings (D 418 – 38 T)
- Testing and Tolerances for Certain Carded Cotton Gray Goods (D 433 – 36 T)
- Testing and Tolerances for Yarns Spun from Wool Mixed with Fibers Other than Wool (D 508 – 38 T)
- Test for Fastness of Colored Textile Fabrics to Light (D 506 – 38 T), as revised
- Testing and Tolerances for Spun Rayon Yarns and Threads (D 507 – 38 T), as revised.
- Revisions of:
  - Testing and Tolerances for Knit Goods (D 231 – 33)
  - Spec. and Tests for Osnaburg Cement Sacks (D 205 – 27)
  - Testing Woven Textile Fabrics (D 39 – 38)
  - Spec. for Textile Testing Machines (D 76 – 37)
  - Testing and Tolerances for Cotton Sewing Threads (D 204 – 36)

TABLE I.–NUMBER OF TESTS.

Physical property	Strength	Yards per pound	Gage	Twist
Number of tests, n	40	10	10	12
Coefficient of variation, V, per cent	7	2	2	4
Precision, per cent	3	2	2	3
Probability	0.99	0.99	0.99	0.99

NOTE.—Information available to the committee indicates that the values given in Table I for coefficient of variation, V, are approximately correct, but if the running level of V based on experience is found to be V_1, the number of tests, n_1, required will be determined from the following formula:

$$n_1 = \frac{V_1^2 \times n}{V^2}$$

In no case shall n_1 be less than n.

Committee D-7 on Timber:

Report presented by Hermann von Schrenk, chairman, and the following actions taken:

Accepted as Tentative:

- Revision of Test for Tar Acids in Creosote and Creosote - Coal-Tar Solutions (D 453 – 38 T)

Adopted as Standard:

- Spec. for Zinc Chloride (D 432 – 36 T)
- Revision of Test for Distillation of Creosote (D 246 – 33)

Committee C-5 on Fire Tests of Materials and Construction:

Informal progress report presented by the Chair in absence of chairman.

Committee D-17 on Naval Stores:

Report presented by C. F. Speh, secretary.

Committee D-10 on Shipping Containers:

Informal progress report presented by the Chair, in absence of chairman.

EIGHTH SESSION—COAL, GASEOUS FUELS, PETROLEUM PRODUCTS

Wednesday, June 28, 2 p.m.

Session Chairman: J. B. Rather

Committee D-5 on Coal and Coke:

Report presented by A. C. Fieldner, chairman.

Sectional Committee M20 on Classification of Coals:

Report presented by A. C. Fieldner, chairman, and the following action taken:

Adopted as Standard:

- Definitions for Varieties of Bituminous and Subbituminous Coals (D 493 – 38 T)

Committee D-3 on Gaseous Fuels:

Report presented by A. C. Fieldner, chairman.

Committee D-2 on Petroleum Products and Lubricants:

Report presented by T. A. Boyd, chairman, and the following actions taken:

Accepted as Tentative:

- Test for Carbon Residue of Petroleum Products (Ramsbottom Carbon Residue), revised as follows:

Section 2 (d).—Change from the form as preprinted to read as follows by the addition of the italicized words and the omission of those in brackets:

(*d*) Temperature-Measuring Devices.—A [suitable] thermocouple or *other suitable temperature-indicating device* located close to the bulb well with the lower end not less than 1 in. (25 mm.) from the bottom of the bath. It is desirable to protect the *temperature-indicating device* [thermocouple or thermometer] with a quartz or thin metal sheath.

Test for Gum Stability of Gasoline, revised as follows:

Section 2 (a).—Change the note following this section from the form as preprinted to read as follows by the omission of the material in brackets:

NOTE.—The material used for construction of the bomb should be 18 per cent chromium, 8 per cent nickel alloy steel conforming to [grade F8 of the Standard Specifications for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for Service at Temperatures from 750 to 1100 F. (A.S.T.M. Designation: A 182) of the American Society for Testing Materials, or to] S.A.E. Nos. 30905 or 30915 corrosion-resistant steels.

Fig. 1.—Insert the dimension of 4⅜ in. as the height of the glass liner.

Test for Tetraethyl Lead in Gasoline

Revisions of:

Test for Color of Lubricating Oils (D 155 - 34 T), and Color of Petrolatum (D 218 - 34 T) by A.S.T.M. Union Colorimeter, combined into one method

Test for Saponification Number (D 94 - 38 T)

Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323 - 38 T)

Test for Kinematic Viscosity (D 445 - 38 T

Revision of Test for Distillation of Plant Spray Oils (D 447 - 37 T); not having been preprinted it was accepted by unanimous consent, subject to favorable letter ballot of Committee D-2,[12] as follows:

Section 6.—Add the following as a new Section 6:

6. The actual barometric pressure shall be ascertained and recorded, but no correction shall be made except in case of dispute. In such cases the temperature points shall be corrected to 760 mm. (29.92 in.) by the use of the Sydney Young equation, as follows:

For Centigrade readings:

$$C_c = 0.00012\ (760 - P)\ (273+t_c)$$

For Fahrenheit readings:

$$C_f = 0.00012\ (760 - P)\ (460+t_f)$$

where:

C_c and C_f = corrections to be added to the observed temperature t_c or t_f, respectively, and

P = actual barometric pressure in millimeters of mercury.

Adopted as Standard:

Test for Acid Heat of Gasoline (D 481 - 38 T), as revised

Test for Knock Characteristics of Motor Fuels (D 357 - 38 T), as revised

Viscosity-Temperature Charts for Liquid Petroleum Products (D 341 - 37 T); this recommendation not having been preprinted, was approved by unanimous consent, subject to favorable letter ballot of Committee D-2[12]

Method for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity (D 446 - 37 T); this recommendation not having been preprinted, was approved by unanimous consent, subject to favorable letter ballot of Committee D-2[12]

Terms Relating to Petroleum (D 288 - 36 T); this recommendation not having been preprinted, was approved by unanimous consent, subject to favorable letter ballot of Committee D-2[12]

Revisions of:

Test for Cloud and Pour Points (D 97 - 34)

Tests for Distillation of Natural Gasoline (D 216 - 32)

Test for Sulfur in Petroleum Oils by Bomb Method (D 129 - 34), with the following additional changes presented on the floor at the annual meeting:

Section 2 (d).—Change from the form as preprinted by the omission of the material in brackets:

(*d*) *Oxygen.*—Oxygen under pressure, and free from combustible material [and containing enough nitrogen to insure complete oxidation of the sulfur in the oil sample. The nitrogen content of the oxygen when the bomb is filled shall represent at least 5 per cent of the total nitrogen and oxygen].

Section 4 (a).—In the second paragraph change "20 ml." to read "5 ml."

Test for Thermal Value of Fuel Oil (D 240 - 27), with changes in Sections 2 (*g*) and

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[12] Committee D-2 reported the following results of the letter ballot vote of a total of 50 ballots returned from a voting membership of 79: D 447, affirmative 41, negative 0; D 341 and D 446, affirmative 49, negative 0; D 288, affirmative 48, negative 0.

3 (*b*) identical with those given above for Sections 2 (*d*) and 4 (*a*) of Method D 129.

Tests for Burning Quality of Kerosine Oils (D 187 - 36), approved by unanimous consent for immediate adoption

Tests for Carbon Residue of Petroleum Products (Conradson Carbon Residue) (D 189 - 36)

Test for Gravity of Petroleum and Petroleum Products by Means of the Hydrometer (D 287 - 37)

Withdrawal of Tentative Standard:

Test for Expressible Oil and Moisture in Paraffin Waxes (D 308 - 29 T)

Publication as Information Only:

Proposed Method of Test for Neutralization Number of Used Aviation Oils

Proposed Specifications for Aviation Gasoline, with editorial changes

The proposed Tentative Method of Doctor Test for Motor Fuels, Naphthas, and Kerosines was withdrawn from the report by the committee.

Sectional Committee Z11 on Petroleum Products and Lubricants:

Report was presented from manuscript by T. A. Boyd, chairman.

Papers:

The following papers were presented:

The Determination of Organic Sulfur in Gases by the Catalytic Hydrolysis Method—Lawrence T. Jilk, presented by the author.

Recent Experiments on Laboratory Wet Gas Meters—Howard S. Bean and F. Charles Morey, presented by Mr. Morey.

NINTH SESSION—MARBURG LECTURE AND DUDLEY MEDAL AWARD

Wednesday, June 28, 4 p.m.

Session Chairman: President T. G. Delbridge.

In introducing the fourteenth Edgar Marburg Lecturer, President Delbridge said that it was indeed a significant pleasure to hear from a Past-President and Honorary Member of the Society and an eminent scientist who had made many notable achievements and contributions in his chosen field of endeavor in the engineering profession. He then presented Herbert F. Moore, Professor of Engineering Materials, University of Illinois, who chose as the subject of the lecture "Stress, Strain and Structural Damage." In the course of his lecture Professor Moore presented a number of interesting observations on this subject in relation to the service and properties of engineering materials. He discussed in detail the problems of measuring four types of structural damage due to mechanical causes, that resulting from elastic deformation from damage by inelastic action, from fracture, and from damage by continuing deformation or creep. Professor Moore pointed out that the metallurgist with microscope and X-ray diffraction apparatus has shown that internal structure of materials is far more complicated than former simplified assumptions; also that the structures of materials seem so complicated that so far no mathematical analyst has proposed rigid formulas which fit all these new viewpoints. He pointed out some of the defects in our present structural theories as they relate to elastic action but indicated that they are adequate for practical purposes when properly applied.

President Delbridge in expressing appreciation to Professor Moore for his fine exposition on a subject of particular interest to the A.S.T.M. presented to him on behalf of the Society the Edgar Marburg Lecture Certificate.

President Delbridge then introduced M. F. Sayre, chairman of the Dudley Medal Committee, who presented as the recipient of the thirteenth award of the Charles B. Dudley Medal, Mr. Roy W. Carlson, Associate Professor of Civil Engineering, Massachusetts Institute of Technology, for his paper on "Drying

Shrinkage of Concrete as Affected by Many Factors," presented at the 1938 Annual Meeting of the Society. Mr. Sayre explained that the Medal is awarded annually by the Society to the author of a technical paper considered of outstanding merit and an original contribution on research in engineering materials. He stated that the committee recognized that the paper presented by Mr. Carlson represented an unusually careful study of broad scope on an important problem dealing with concrete and eminently merits the recognition conveyed by the Dudley Medal Award.

On behalf of and as the representative of the Society, President Delbridge then made the Thirteenth Award of the Charles B. Dudley Medal to Mr. Carlson.

In accepting the Medal, ~~Mr.~~ Carlson stated that he greatly appreciated the recognition accorded by the Award of the Dudley Medal, and in accepting the Medal with due appreciation of the honor which accompanies it, he expressed a wish that he may find it possible to continue the studies at some time in the near future.

TENTH SESSION—METALLOGRAPHY, MAGNETIC TESTING, RADIOGRAPHY

Wednesday, June 28, 8 p.m.

Session Co-Chairmen: John Howe Hall; H. E. Seemann.

Committee E-4 on Metallography:

Report presented by L. L. Wyman, chairman, and the following action taken:

Accepted as Tentative:

Method of Preparation of Metallographic Specimens (E 3 – 39 T); to replace the present Standard E 3 – 36

Committee A-6 on Magnetic Properties:

Report presented by Thomas Spooner, chairman, and the following actions taken:

Accepted as Tentative:

Test for Measuring Lamination Factor of Steel (A 34 – 39 T); with the dimension of "$9\frac{27}{32}$" in Section 2 (*a*) corrected to read "$8\frac{15}{32}$"

Revision of Terms, with Units and Symbols, Relating to Magnetic Testing (A 127–36), five new definitions.

Adopted as Standard:

Revision of Test for Magnetic Properties of Iron and Steel (A 34 – 38)

Revision of Terms, with Units and Symbols, Relating to Magnetic Testing (A 127 – 36), one new and two revised definitions.

Committee E-7 on Radiographic Testing:

Report presented from manuscript by H. H. Lester, chairman.

Papers:

After the presentation of the reports, the session adjourned to be reconvened as two separate sessions—one, under the chairmanship of John Howe Hall, for the presentation of papers on metallography and magnetic analysis; the other session, under the chairmanship of H. E. Seemann, for the presentation of the papers on radiography. The papers are listed below:

Metallography and Magnetic Analysis

Metallography in Color[12a]—R. P. Loveland, presented by the author.

Magnetic Analysis Applied to the Inspection of Bar Stock and Pipe[13]—Theodor Zuschlag, presented by the author.

Some Mechanical Tests on Aluminum Alloys 14S-T and 24S-T—W. B. Mechling and S. S. Jack, presented by W. Lavern Howland.

Radiography

Correlation of Some Mechanical Tests of Aluminum Alloys with X-ray Tests—Tom A.

[12a] This paper does not appear in the *Proceedings*. It is expected to be published at a later date.

[13] Published in ASTM BULLETIN, No. 99, August, 1939, p. 35.

Triplett and W. Lavern Howland, presented by Mr. Triplett.

The Use of Radiography in the Development of Castings for Mass Production[14]—Don M. McCutcheon, presented by J. L. McCloud.

Some Aspects of Radiographic Sensitivity in Testing with X-rays[15]—H. H. Lester, presented by the author.

Fine Focus Radiography—Gamma Rays—Gilbert E. Doan and Milton B. Vordahl, presented by Mr. Doan.

ELEVENTH SESSION—SOILS

Wednesday, June 28, 8 p.m.

Session Co-Chairmen: F. J. Converse; Gregory P. Tschebotareff.

Committee D-18 on Soils for Engineering Purposes:

Report presented by H. F. Clemmer, chairman, and the following actions taken:

Adopted as Standard:

Method of Preparing Soil Samples as Received from the Field for Mechanical Analysis and the Determination of the Subgrade Soil Constants (D 421 - 38 T)
Method of Mechanical Analysis of Soils (D 422 - 38 T)
Test for Liquid Limit of Soils (D 423 - 38 T)
Test for Plastic Limit and Plasticity Index of Soils (D 424 - 38 T)
Test for Centrifuge Moisture Equivalent of Soils (D 425 - 38 T)
Test for Field Moisture Equivalent of Soils (D 426 - 38 T)
Test for Shrinkage Factors of Soils D 427 - 38 T)

Symposium on Shear Testing of Soils:

The Symposium on Shear Testing of Soils was sponsored by Committee D-18 on Soils for Engineering Purposes in order to bring before the engineering profession the most recent developments in this phase of soil mechanics, and to provide those interested in the problem with an opportunity to discuss and coordinate their ideas.

Six papers comprised the symposium, as follows:[16]

Torsional Shear Tests and Their Place in the Determination of the Shearing Resistance of Soils—M. Juul Hvorslev presented by the author.

Some Practical Aspects of Soil Shear Testing—Gregory P. Tschebotareff, presented by the author.

Principles of Triaxial Shear Tests—C. A. Hogentogler and E. S. Barber, presented by Mr. Hogentogler.

A Triaxial Compression Apparatus for the Determination of the Stress-Deformation Characteristics of Soils—John D. Watson, presented by the author.

A Comparison of Results of Direct Shear and Cylindrical Compression Tests—Donald W. Taylor, presented by the author.

Shearing Resistance of Cohesive Soil—Its Measurement and Practical Significance—W. S. Housel, presented by the author.

TWELFTH SESSION—STEEL, FERRO-ALLOYS, EFFECT OF TEMPERATURE

Thursday, June 29, 9.30 a.m.

Session Co-Chairmen: Vice-President H. H. Morgan; Past-President A. E. White.

Committee A-1 on Steel:

Report presented by N. L. Mochel, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Alloy Steel Boiler and Superheater Tubes
Spec. for Electric Resistance Welded Steel Heat-Exchanger and Condenser Tubes
Spec. for Carbon-Steel Castings for Miscellaneous Industrial Uses Suitable for Fusion Welding

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[14] Published in ASTM BULLETIN, No. 103, March, 1940.

[15] Published in ASTM BULLETIN, No. 100, October, 1939, p. 33.

[16] Material presented as discussion is published with the papers comprising the Symposium on Shear Testing of Soils as two additional formal papers, as follows:

Some Investigations of the Shearing Resistance of Cohesionless and Cohesive Materials, by D. M. Burmister.

The Effects of Internal Hydrostatic Pressure on the Shearing Strength of Soils, by L. W. Hamilton.

Spec. for Carbon-Steel Castings Suitable for Fusion Welding for Service at Temperatures up to 850 F.
Spec. for Alloy-Steel Castings Suitable for Fusion Welding for Service at Temperatures from 750 to 1100 F.
Revisions of:
  Spec. for Heat-Treated Carbon- and Alloy-Steel Track Bolts (A 183 - 36 T)
  Spec. for High-Strength Structural Rivet Steel (A 195 - 36 T)
  Spec. for Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A 206 - 38 T)
  Spec. for Boiler and Firebox Steel for Locomotives (A 30 - 38)

Adopted as Standard:

Spec. for High-Carbon-Steel Joint Bars (A 5 - 36 T)
Spec. for Quenched Carbon-Steel Joint Bars (A 49 - 36 T)
Spec. for Normalized Quenched-and-Tempered Alloy-Steel Forgings (A 63 - 38 T) as revised
Spec. for One-Wear and Two-Wear Wrought Steel Wheels (A 186 - 36 T), as revised
Spec. for Carbon-Steel Castings for Miscellaneous Industrial Uses (A 27 - 36 T)
Spec. for Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 - 37 T)
Spec. for Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 37 T)
Spec. for Low-Carbon-Nickel Steel Plates for Boilers and Other Pressure Vessels (A 203 - 37 T)
Spec. for Carbon and Alloy-Steel Nuts for Bolts for High-Pressure and High-Temperature Service to 1100 F. (A 194 - 38 T)
Spec. for Steel for Bridges and Buildings (A 7 - —); representing a revision and consolidation of existing Specs. A 7 - 36 and A 9 - 36, with the following additional change, not preprinted, accepted by unanimous consent, subject to favorable letter ballot of Committee A-1:[17]

Section 3.—Add the following as a new Section 3, renumbering the present sections accordingly:

3. *Structural Bolts.*—Unless otherwise specified, bolts to be employed in permanent connections between parts fabricated of steel purchased under these specifications shall be subject to the requirements of Section 9 (*a*) hereof for minimum tensile strength (to be taken on the area at root of thread) and to the requirements of Section 10 hereof for cold bend (to be taken on the unthreaded portion of the bolt), and shall be exempt from further requirements.

Spec. for High Tensile Strength Carbon-Steel Plates for Pressure Vessels (Plates 4½ in. and Under in Thickness), representing a revision and consolidation of the existing Standards A 149 - 38 and A 150 - 38
Revisions of:
  Spec. for Open-Hearth Carbon-Steel Rails (A 1 - 36)
  Spec. for Carbon-Steel Bars for Railway Springs (A 14 - 27)
  Spec. for Silico-Manganese-Steel Bars for Railway Springs (A 59 - 27)
  Spec. for Chrome-Vanadium-Steel Bars for Railway Springs (A 60 - 27)
  Spec. for Carbon-Steel Bars for Railway Springs with Special Silicon Requirements (A 68 - 36)
  Spec. for Helical Steel Springs for Railways (A 61 - 16)
  Spec. for Heat-Treated Carbon-Steel Helical Springs (A 125 - 33)
  Spec. for Elliptical Steel Springs for Railways (A 62 - 16)
  Spec. for Heat-Treated Steel Elliptical Springs (A 147 - 35)
  Spec. for Multiple-Wear Wrought Steel Wheels (A 57 - 36)
  Spec. for Steel Tires (A 26 - 16)
  Spec. for Boiler Rivet Steel and Rivets (A 31 - 36)[18]
  Spec. for Open-Hearth Iron Plates of Flange Quality (A 129 - 33)
  Spec. for Steel Plates of Flange and Firebox Qualities for Forge Welding (A 89 - 33)
  Spec. for Carbon-Silicon-Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 - 38)
  Spec. for Alloy-Steel Castings for Valves, Flanges and Fittings for Service at Temperatures from 750 to 1100 F. (A 157 - 36)
  Spec. for Forged or Rolled Steel Pipe Flanges for High-Temperature Service (A 105 - 36)

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[17] Committee A-1 reported results of the letter ballot vote as follows: Of a total membership of 222, 183 members returned their ballots, of whom 103 voted affirmatively, 0 negatively.

[18] On the recommendation of Committee A-1 on Steel, the Executive Committee at its October, 1939, meeting approved postponement of this action.

Spec. for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for Service at Temperatures from 750 to 1100 F. (A 182 – 36)

Spec. for Lap-Welded and Seamless Steel Pipe for High-Temperature Service (A 106 – 36)

Spec. for Billet-Steel Concrete Reinforcement Bars (A 15 – 35)

Spec. for Axle-Steel Concrete Reinforcement Bars (A 160 – 35)

Spec. for Electric-Fusion-Welded Steel Pipe (Sizes 30 in. and Over) (A 134 – 36)

Spec. for Electric-Fusion-Welded Steel Pipe (Sizes 8 in. to but not Including 30 in.) (A 139 – 36)

Spec. for Iron and Steel Chain (A 56 – 30)

Spec. for Alloy-Steel Bolting Material for High-Temperature Service (A 96 – 33), with the following additional change, not preprinted, accepted by unanimous consent, subject to favorable letter ballot of Committee A-1:[19]

Section 13.—Add a new paragraph (*a*) to read as follows, relettering the subsequent paragraphs accordingly:

(*a*) For bars, one tension test shall be made from each tempering charge. If more than one heat treatment charge is represented in a tempering charge, one tension test shall be made from each heat treatment charge. If more than one melt is represented in a heat treatment charge, one tension test shall be made from each melt.

Change the relettered paragraphs (*b*), (*c*) and (*e*) to read as follows by the addition of the italicized material and the omission of that in brackets (no change in paragraph (*d*)):

(*b*) Except as specified in Paragraph (*c*) one tension test shall be made for each lot of *300* [100] pieces or fraction thereof of *bolts, screws and studs for sizes up to and including 2½ in. in diameter; or for each lot of 100 pieces or fraction thereof for sizes over 2½ in.* [bolting material from each tempering charge. If more than one quenching charge is represented in a tempering charge, one tension test shall be made from each lot of 100 pieces or fraction thereof from each quenching charge. If more than one melt is represented in a quenching charge, one tension test shall be made from each lot of 100 pieces or fraction thereof from each melt.]

(*c*) Unless required on the order, tension tests shall not be made on an order of less *quantity than specified in Paragraph* (*b*) [than 100 bolts, screws or studs]; in which case acceptance shall be based upon the provisions in Section 2 or 3.

(*e*) If the percentage of elongation of any *tension* test specimen is less than that specified in Section 10 (*a*) and any part of the fracture is *more than 3/4 in. from the center* [outside of the middle three-fourths] of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

Tables of permissible variations in dimensions and weight of steel plates and shapes, for inclusion in the following Specifications: A 8 – 38, A 141 – 38, A 7 – 36, A 9 – 36, A 10 – 34, A 113 – 33, A 94 – 36, A 78 – 33, A 195 – 36 T, A 203 – 37 T, A 114 – 33, A 14 – 27, A 59 – 27, A 60 – 27, A 68 – 36, A 30 – 38, A 149 – 38, A 150 – 38, A 201 – 38, A 202 – 38, A 204 – 38, A 131 – 36, A 31 – 36, A 70 – 36, A 129 – 33, A 89 – 33, A 107 – 36

Withdrawal of Standards and Tentative Standards:

Spec. for Steel for Buildings (A 9 – 36)

Spec. for Quenched-and-Tempered Alloy-Steel Axles, Shafts and Other Forgings for Locomotives and Cars (A 63 – 36)

Spec. for Quenched-and-Tempered Carbon-Steel Axles, Shafts and Other Forgings for Locomotives and Cars (A 19 – 36)

Spec. for Carbon-Steel Forgings for Locomotives (A 20 – 31 T)

Spec. for High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates 2 in. and Under in Thickness) (A 149 – 38)

Spec. for High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates over 2 to 4½ in., Inclusive, in Thickness) (A 150 – 38)

Reaffirmation of Standards:

Spec. for Manufacture of Open-Hearth Steel Girder Rails of Plain, Grooved and Guard Types (A 2 – 27)

Spec. for Low-Carbon-Steel Splice Bars (A 3 – 33)

Spec. for Medium-Carbon-Steel Splice Bars (A 4 – 14)

Spec. for Soft Steel Track Spikes (A 65 – 33)

Spec. for Steel Tie Plates (A 67 – 33)

Spec. for Low-Carbon-Steel Track Bolts (A 76 – 33)

Spec. for Steel Screw Spikes (A 66 – 33)

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[19] Committee A-1 reported results of the letter ballot vote as follows: Of a total membership of 222, 176 members returned their ballots, of whom 94 voted affirmatively, 0 negatively.

The Spec. for Carbon-Steel Forgings, proposed as a revision of the existing Standard A 18 – 30, were withdrawn from the report by the committee.

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys:

Report presented by Jerome Strauss, chairman, and the following actions taken:

Adopted as Standard:

- Spec. for 12 per cent Chromium Steel Castings (A 168 – 35 T)
- Spec. for 19 per cent Chromium Steel Castings (A 169 – 35 T)
- Spec. for 28 per cent Chromium Steel Castings (A 170 – 35 T)
- Spec. for 24 per cent Chromium, 12 per cent Nickel Alloy Steel Castings (A 171 – 35 T)
- Spec. for 25 per cent Chromium, 20 per cent Nickel Alloy Steel Castings (A 172 – 35 T)
- Spec. for 28 per cent Chromium, 9 per cent Nickel Alloy Steel Castings (A 173 – 35 T)
- Spec. for 20 per cent Nickel, 9 per cent Chromium Alloy Steel Castings (A 174 – 35 T)
- Spec. for 35 per cent Nickel, 15 per cent Chromium Alloy Steel Castings (A 175 – 35 T)
- Spec. for 20 per cent Chromium, 9 per cent Nickel Alloy Steel Castings (A 198 – 36 T)
- Spec. for Corrosion-Resisting Chromium-Nickel Steels (Sheet, Strip and Plate) (A 167 – 38 T), as revised
- Revisions of:
  - Spec. for Corrosion-Resisting Chromium Steels (Sheet, Strip, and Plate) (A 176 – 38)
  - Spec. for High-Strength Corrosion-Resisting Chromium-Nickel Steels (Sheet and Strip) (A 177 – 38)

Publication as Information Only:

Proposed Guide for Conducting Plant Corrosion Tests; attention was called to the fact that the committee plans to submit the Guide to the Society for publication as tentative through Committee E-10 on Standards subsequent to the annual meeting.

Sectional Committee B36 on Standardization of Dimensions and Materials of Wrought-Iron and Wrought-Steel Pipe and Tubing:

Report presented by H. H. Morgan, chairman.

Committee A-9 on Ferro-Alloys:

Report presented from manuscript, in the absence of the chairman, by E. A. Lucas, and the following actions taken:

Accepted as Tentative:

- Revision of Spec. for Spiegeleisen (A 98 – 38 T)
- Revision of Spec. for Ferrochromium (A 101 – 38 T)

Adopted as Standard:

- Revisions of:
  - Spec. for Ferromanganese (A 99 – 27)
  - Spec. for Ferrosilicon (A 100 – 27)
  - Spec. for Ferrovanadium (A 102 – 27)
  - Spec. for Ferromolybdenum (A 132 – 34)
  - Spec. for Low-Carbon Ferromolybdenum (A 145 – 34)
  - Spec. for Ferrotungsten (A 144 – 34)
  - Spec. for Molybdenum Salts and Compounds (A 146 – 34)

Withdrawal of Standards:

- Spec. for Spiegeleisen (A 98 – 27)
- Spec. for Ferrochromium (A 101 – 27)

Joint Research Committee on Effect of Temperature on the Properties of Metals:

Report presented by N. L. Mochel, chairman, and the following papers, appended to the report, were presented as indicated:

- Report on Torsion Creep Tests for Comparison with Tension Cr[illegible] Tests on a Carbon-Molybden[illegible] Everett and C. L. Clark, [illegible]ed by A. E. White.
- Report on Further Experiments with a Proposed Acceptance Test: Effect of Grain Size—C. L. Clark and A. E. White, presented by Mr. White.
- Correlation of Test Results for Various Types of High-Temperature Tests Carried out for the Joint Research Committee—E. A. Davis, presented by the author.

Papers:

The following papers were presented:

A Work-Brittleness Test for Steel—H. W. Graham and H. K. Work, presented by C. C. Henning.

The Alloy Casting Research Institute Test Block for Heat-Resisting Alloys; Its History, Selection and Utilization—O. E. Harder, presented by the author.

Nickel-Molybdenum-Iron and Related Alloys—Their Physical and Corrosion-Resistant Properties—F. T. McCurdy, presented by the author.

THIRTEENTH SESSION—BITUMINOUS MATERIALS, ROAD MATERIALS

Thursday, June 29, 9.30 a.m.

Session Co-Chairmen: President T. G. Delbridge; J. M. Weiss.

Committee D-8 on Bituminous Waterproofing and Roofing Materials:

Report presented by J. M. Weiss, chairman, and the following actions taken:

Accepted as Tentative:

- Spec. for Asphalt Mastic for Use in Waterproofing (Asphalt Cement, Mineral Filler, Mineral Aggregate), to replace Specs. D 169 - 25, D 223 - 30 and D 491 - 38 T
- Recommended Practice for Accelerated Weathering Test of Bituminous Materials
- Revisions of:
  - Spec. for Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 - 38 T)
  - Spec. for Asphalt for Use in Constructing Built-up Roof Coverings (D 312 - 37 T)
  - Spec. for Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 - 27)
  - Spec. for Asphalt-Saturated Asbestos Felt for Use in Constructing Built-Up Roofs (D 250 - 27)

Committee D-4 on Road and Paving Materials:

Report presented by E. F. Kelley, chairman, and the following actions taken:

Accepted as Tentative:

- Revisions of:
  - Spec. for Crushed Stone for Bituminous Macadam Base and Surface Courses (D 192 - 38 T)
  - Spec. for Crushed Slag for Bituminous Macadam Base and Surface Courses (D 487 - 38 T)
  - Spec. for Crushed Stone for Bituminous Concrete Base and Surface Courses (D 486 - 38 T)

Adopted as Standard:

- Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 36 T)
- Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 36 T)
- Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 38 T), as revised
- Test for Sieve Analysis of Fine and Coarse Aggregates (C 136 - 38 T)
- Spec. for Mineral Filler for Sheet Asphalt and Bituminous Concrete Pavements (D 242 - 26 T), as revised
- Testing Emulsified Asphalts (D 244 - 36 T), as revised
- Recommended Practice for Bituminous Paving Plant Inspection (D 290 - 28 T), as revised
- Spec. for Emulsified Asphalt (for Coarse Aggregate Plant Mixes) (D 397 - 36 T), as revised
- Spec. for Emulsified Asphalt (for Retread and Coarse Aggregate Mixes) (D 398 - 36 T), as revised
- Spec. for Emulsified Asphalt (Heavy Premix—Summer Grade) (D 399 - 36 T), as revised

The following editorial change in Specifications D 397, D 398, and D 399 was presented on the floor at the annual meeting and accepted:

Section 3.—Change the last sentence to read as follows by the addition of the italicized material and the omission of that in brackets:

Prior to any shipments being made on projects requiring 20,000 gal. or more [The] *a* sample shall be taken under the supervision of the purchaser, from [factory storage containing] *a lot of* not less than 20,000 gal. of the emulsified asphalt and shall be kept in a clean airtight sealed [glass or black iron] container at a temperature of not less than 4 C. (40 F.) until tested.

Revisions of:

- Test for Ductility of Bituminous Materials (D 113 – 35)
- Spec. for Block for Granite Block Pavements (D 59 – 26)
- Spec. for Block for Recut Granite Block Pavements (D 131 – 23)
- Spec. for Block for Durax Granite Pavements (D 132 – 23)

The recommendations with respect to Specs. D 59, D 131 and D 132, not having been preprinted, were approved by unanimous consent, subject to favorable letter ballot of Committee D-4.[20]

Withdrawal of Tentative Standards:

- Spec. for Asphalt Cement, 10 to 15 Penetration, for the Manufacture of Asphalt Block (D 133 – 23 T)
- Spec. for Asphalt Cement, 15 to 25 Penetration, for the Manufacture of Asphalt Block (D 134 – 23 T)
- Spec. for Asphalt Cement, 25 to 30 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements (D 163 – 23 T)
- Spec. for Asphalt Cement, 30 to 40 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements (D 164 – 23 T)
- Spec. for Asphalt Cement, 40 to 50 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements and as Filler for Brick and Block Pavements (D 99 – 26 T)
- Spec. for Asphalt Cement, 50 to 60 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements and as Filler for Block Pavements (D 100 – 26 T)
- Spec. for Asphalt Cement, 60 to 70 Penetration, for Use in Sheet Asphalt, Asphaltic-Concrete and Asphalt-Macadam Pavements and as Filler for Block Pavements (D 101 – 26 T)
- Spec. for Asphalt Cement, 85 to 100 Penetration, for Use in Asphalt-Macadam Pavements (D 102 – 24 T)
- Spec. for Asphalt Cement, 100 to 120 Penetration, for Use in Asphalt-Macadam Pavements (D 103 – 24 T)
- Spec. for Asphalt Cement, 120 to 150 Penetration, for Use in Asphalt-Macadam Pavements (D 135 – 23 T).

Reversion of Standards to Tentative:

- Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials, Including Some Material Survey Methods (D 75 – 22)
- Sampling Bituminous Materials (D 140 – 25)
- Test for Loss on Heating of Oil and Asphaltic Compounds (D 6 – 33)

It was announced that the recommendation for publication as information of the Proposed Specifications for Emulsion for Use in Densely Graded Cold Asphaltic Mixes was to be resubmitted to letter ballot of Committee D-4, the ballot to be accompanied by prepared statements concerning the specifications. Action was also taken by the committee to submit to letter ballot of its membership a proposal to retain the test methods in the report as information in case the proposed specifications should not be approved. On motion, these recommendations, to be accompanied by the results of the letter ballots when completed, were referred to the Executive Committee of the Society.[20a]

The proposed revision and adoption as standard of Spec. for Emulsified Asphalt ((Quick Setting) for Penetration and Surface-Treatment) (D 401 – 36 T) was withdrawn from the report by the committee. The following editorial change in these specifications was presented on the floor at the annual meeting and accepted:

Section 3.—Change the last sentence to read as follows by the addition of the italicized material and the omission of that in brackets:

Prior to any shipments being made on projects requiring 20,000 gal. or more [The] *a* sample shall be taken under the supervision of the purchaser, from [factory storage containing] *a lot of* not less than 20,000 gal. of the emulsified asphalt and shall be kept in a clean airtight sealed [glass or black iron] container at a temperature of not less than 4 C. (40 F.) until tested.

The following editorial changes in the Spec. for Asphalt Plank (D 517 – 38 T) were presented on the floor at the annual meeting and accepted:

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[20] Committee D-4 reported the following results of the letter ballot vote of a total of 91 ballots returned from a voting membership of 117: D 59, affirmative 47, negative 0; D 131 and D 132, affirmative 46, negative 0.

[20a] The Executive Committee subsequently authorized the publication of the methods in the ASTM BULLETIN, No. 101, December, 1939, p. 34, but withheld the specifications from publication. ED.

Section 1.—Add the following note to the section on scope:

NOTE.—Plain asphalt plank meeting these specifications are also suitable for water-proofing protection where a solid bridge floor carries ballasted railroad track.

The following editorial change in the Test for Softening Point of Bituminous Materials (Ring-and-Ball Method) (D 36 - 36) was presented on the floor at the annual meeting and accepted:

Section 3.—Change to read as follows by the addition of the italicized material:

After cooling *1 hr.* the excess material shall be cut off cleanly with a slightly heated knife.

Papers:

The following papers were presented:

Evaluating the Adhesive Properties of Asphalt—August Holmes, presented by the author.

Research in Soil Stabilization with Emulsified Asphalt—C. L. McKesson, presented by the author.

Some Factors Affecting the Thermal Susceptibility of Asphaltic Paving Mixtures—Roland Vokac, presented by the author.

Degradation of Aggregates Under Road Rollers—Tilton E. Shelburne, presented from manuscript by the author.

ROUND-TABLE DISCUSSION ON FUNDAMENTAL METHODS AND TECHNIQUE OF SPECTROCHEMICAL ANALYSIS

Thursday, June 29, 9.30 a.m. and 1.30 p.m.

Session Chairman: H. V. Churchill.

Session Co-Chairmen: O. S. Duffendack; A. E. Ruehle; M. L. Fuller.

The Discussion on Fundamental Methods and Technique of Spectrochemical Analysis was sponsored by Committee E-2 on Spectrographic Analysis preliminary to a more formal symposium at the 1940 Annual Meeting.

The two sessions devoted to this preliminary round-table discussion, were divided as follows, certain individuals having been selected to lead the discussion on these various phases of the subject:

I. Fundamental Methods of Analysis:
    1. Methods of Qualitative and Semi-Quantitative Analysis.
    2. Method of Direct Comparison with Standards.
    3. Method of External Control.
    4. Method of Internal Control.
II. Methods of Excitation:
    1. Flame.
    2. The Arc: (*a*) Self electrodes; (*b*) supporting electrodes; (*c*) liquid electrodes.
    3. The Spark.
    4. The Glow Discharge.
III. Methods of Spectrophotometry:
    1. Comparison of Line Intensities Without a Calibration Curve.
    2. Plate Calibration: (*a*) With rotating sectors; (*b*) with step-slit; (*c*) with measured spectral lines.

ROUND-TABLE DISCUSSION ON FREEZING-AND-THAWING TESTS

Thursday, June 29, 2 p.m.

Session Chairman: C. H. Scholer.

The Discussion on Freezing-and-Thawing Tests was arranged in view of the fact that although such tests have been applied to various types of material, such as ceramic materials, and concrete, a number of moot points still remain, having to do not only with the variables of the tests but also with the evaluation of the test results.

Two formal papers submitted for the annual meeting program were of definite interest, since they dealt with certain phases of durability, and were accordingly presented as a part of the round-table discussion: namely,

The Effect of Variations in Method upon the Results of Freezing and Thawing Mortars—Bert Meyers, presented by Stanton Walker.

The Effect of Biot's Modulus on Transient Thermal Stresses in Concrete Cylinders—Gerald Pickett, presented by the author.

There followed a spirited discussion, at the conclusion of which the sentiment was crystallized in the form of a resolution to the effect that it was the sense of the meeting that a committee be organized under the proper auspices of the Society, as for example Committee E-1 on Methods of Testing, to continue studies of freezing-and-thawing tests, looking toward the establishment of a suitable standard procedure, with the understanding that this committee would act as a clearing house for information on freezing-and-thawing tests, and serve in an advisory capacity to the interested standing committees.

FOURTEENTH SESSION—CERAMIC AND MASONRY MATERIALS

Thursday, June 29, 8 p.m.

Session Chairman: M. O. Withey.

Committee C-8 on Refractories:

Report presented, in the absence of the chairman, by the Secretary-Treasurer, and the following actions taken:

Accepted as Tentative:

- Test for Fireclay and Alumina-Diaspore Refractories Under Load at High Temperatures (C 16 – — T)
- Revisions of:
  - Test for Size, Warpage, and Bulk Specific Gravity of Refractory Brick (C 134 – 38 T)
  - Testing High-Temperature Heat Insulation (Compression, Flexure, Shrinkage) (C 93 – 34 T)
  - Panel Test for Resistance to Thermal and Structure Spalling of High Heat Duty Fireclay Brick (C 107 – 36)
  - Panel Test for Resistance to Thermal and Structure Spalling of Super Duty Fireclay Brick (C 122 – 37)

Adopted as Standard:

- Test for Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (C 133 – 37 T)
- Chemical Analysis of Refractory Materials (C 18 – 37 T)
- Symbols for Heat Transmission (C 108 – 34 T)
- Terms Relating to Refractories (C 71 – 37 T), three definitions
- Revisions of:
  - Spec. for Fireclay Brick for Malleable Furnaces with Removable Bungs and for Annealing Ovens (C 63 – 36)
  - Spec. for Fireclay Brick for Stationary Boiler Service (C 64 – 36)
  - Spec. for Refractories for the Construction of Incinerators (C 106 – 36)

Withdrawal of Standards:

- Spec. for Fireclay Brick for Marine Boiler Service (C 65 – 28)
- Test for Refractory Materials Under Load at High Temperatures (C 16 – 36)

Committee C-15 on Manufactured Masonry Units:

Report presented by D. E. Parsons, chairman, and the following actions taken:

Accepted as Tentative:

- Spec. for Solid Load-Bearing Concrete Masonry Units
- Revisions of:
  - Spec. for Sewer Brick (Made from Clay or Shale) (C 32 – 37 T)
  - Spec. for Building Brick (Made from Clay or Shale) (C 62 – 37 T)
  - Spec. for Glazed Building Units (C 126 – 37 T)

Adopted as Standard:

- Sampling and Testing Concrete Masonry Units (C 140 – 38 T)
- Spec. for Sand-Lime Building Brick (C 73 – 38 T)
- Spec. for Concrete Masonry Units for Use in the Construction of Catch Basins and Manholes (C 139 – 38 T)
- Spec. for Hollow Non-Load-Bearing Concrete Masonry Units (C 129 – 38 T), as revised
- Spec. for Structural Clay Load-Bearing Wall Tile (C 34 – 38 T), with the following revision, not preprinted, accepted by unanimous consent, subject to favorable letter ballot of Committee C-15:[21]

Section 4 (c).—Add the following sentence to this section:

If no cell in side construction tile, measured in the direction of the wall thickness, exceeds four times the average overall thickness of either the upper or lower bearing shells, the requirements for minimum shell and web thickness specified in paragraph 4 (*b*) shall be waived.

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[21] Committee C-15 reported results of the letter ballot vote as follows: Of a total membership of 52, 40 members returned their ballots, of whom 37 voted affirmatively, 1 negatively.

Revision of Methods of Testing Brick (C 67 - 37)

Revision of Spec. and Tests for Load-Bearing Concrete Masonry Units (C 90 - 36)

The paper on "Disintegration of Face Brick by Crystallization of Soluble Salt," by J. M. Hardesty, appended to the report, was presented by the author.

Committee C-18 on Natural Building Stones and Slate:

Progress report presented by Theodore I. Coe, chairman.

Committee C-12 on Mortars for Unit Masonry:

Report presented by J. W. McBurney, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Aggregate for Masonry Mortar

The following items were withdrawn from the report by the committee:

Primer on Specifications and Tests for Masonry Mortar

Proposed Spec. for Mortar for Unit Masonry

Papers:

The following papers were presented:

Photoelastic Analysis of a Prestressed Beam—F. O. Anderegg, Royal Weller and B. Fried, presented by Mr. Anderegg.

Sonic Method of Determining the Modulus of Elasticity of Building Materials Under Pressure—Leonard Obert, presented by the author.

FIFTEENTH SESSION—METHODS OF TESTING

Thursday, June 29, 8 p.m.

Session Co-Chairmen: R. L. Templin; Past-President H. F. Moore.

Committee E-1 on Methods of Testing:

Report presented by H. F. Moore, vice-chairman, and the following actions taken:

Accepted as Tentative:

Spec. for A.S.T.M. Thermometers (E 1 - 39 T)

Revision of Test for Softening Point by Tapered Ring Apparatus (E 28 - 36 T)

Adopted as Standard:

Spec. for A.S.T.M. Thermometers (E 1 - 39)

Spec. for Sieves for Testing Purposes (Wire Cloth Sieves, Round-Hole and Square-Hole Screens or Sieves) (E 11 - 38 T), as revised

Bend Testing for Ductility of Metals (E 16 - 38 T), as revised

Sectional Committee Z23 on Specifications for Sieves for Testing Purposes:

Informal report presented by L. T. Work, chairman, announcing that Specifications for Sieves prepared by the sectional committee and now receiving approval by the Society as A.S.T.M. Standard on the recommendation of Committee E-1, would shortly be submitted to the American Standards Association for approval as American Standard.

Papers:

The following papers were presented:

Rockwell Hardness of Cylindrical Specimens—W. E. Ingerson, presented by the author.

Analysis of Rockwell Hardness Data—R. L. Peek, Jr., and W. E. Ingerson, presented by Mr. Peek.

Stress-Strain-Time Characteristics of Materials[22]—Glenn Murphy, presented by the author.

A Study of the Influence of Speed on the Torsion Impact Test—O. V. Greene and R. D. Stout, presented by Mr. Greene.

Load-Weighing and Load-Indicating Systems[23]—C. H. Gibbons, presented by the author.

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[22] Published in ASTM BULLETIN, No. 101, December, 1939, p. 19.

[23] Published in ASTM BULLETIN, No. 100, October, 1939, p. 7.

Tension Specimen Shape and Apparent Strength—F. O. Anderegg, Royal Weller and B. Fried, presented by Mr. Anderegg.

A slow-motion film entitled "The Use of the High-Speed Motion Picture Camera as a Tool in Materials Testing" was shown through the courtesy of the Bell Telephone Laboratories.

SIXTEENTH SESSION—CEMENT, LIME, GYPSUM, CONCRETE

Friday, June 30, 9.30 a.m.

Session Chairman: R. W. Crum.

Committee C-1 on Cement:

Report presented by P. H. Bates, chairman, and the following actions taken:

Accepted as Tentative:

Revision of Method of Chemical Analysis of Portland Cement (C 114 – 38 T), comprising new alternate procedures for determining free calcium oxide in cement.

Adopted as Standard:

Revision of Spec. for High-Early-Strength Portland Cement (C 74 – 38)
Revision of Methods of Sampling and Testing Portland Cement (C 77 – 38), addition of test for specific gravity and recommended order and manner of reporting chemical determinations

A motion for the acceptance as tentative of the new Method of Test for Autoclave Expansion of Portland Cement failed to receive the necessary two-thirds vote of those voting at the session, the result of the vote being 34 affirmative and 20 negative.

Committee C-7 on Lime:

Report presented by J. R. Withrow, chairman, and the following actions taken:

Adopted as Standard:

Spec. for Sand for Use in Plaster (C 35 – 36 T), as revised
Revision of Definitions of Terms Relating to Lime (C 51 – 38), definition of hydrated lime
Revision of Spec. for Quicklime for Use in Water Treatment (C 53 – 27), and for Hydrated Lime for Use in Water Treatment (C 54 – 27), combined into a single standard

Committee C-11 on Gypsum:

Report presented by the Chair, in the absence of the chairman, and the following actions taken:

Accepted as Tentative:

Revision of Testing Gypsum and Gypsum Products (C 26 – 33)

Adopted as Standard:

Spec. for Sand for Use in Plaster (C 35 – 36 T), as revised
Revisions of:
  Definitions of Terms Relating to the Gypsum Industry (C 11 – 28)
  Spec. for Gypsum Plasters (C 28 – 30)
  Testing Gypsum and Gypsum Products (C 26 – 33)

Sectional Committee A42 on Specifications for Plastering:

Progress report presented from manuscript by J. W. McBurney, secretary.

Papers:

The following papers were presented:

Specific Surface and Particle Size Distribution of Finely Divided Materials—M. N. States, presented by the author.

Measurement of Average Particle Size by Sedimentation and Other Physical Means[24]—Pierce M. Travis, presented from manuscript by the author.

A Study of the Effect of Cement Content, Cement Fineness on Compressive Strength, Durability, and Volume Change of Concrete—Ernst Gruenwald, presented from manuscript by the author.

A Flow Method for the Determination of the Effects of Soluble Chemicals on Concrete—Dalton G. Miller, Charles F. Rogers and Philip W. Manson, presented by Mr. Miller.

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[24] Published in ASTM BULLETIN, No. 102, January, 1940, p. 29.

SEVENTEENTH SESSION—CONCRETE

Friday, June 30, 2 p.m.

Session Co-Chairmen: A. T. Goldbeck; H. S. Mattimore.

Committee C-9 on Concrete and Concrete Aggregates:

Report presented, in the absence of the chairman, by R. W. Crum, and the following actions taken:

Accepted as Tentative:

- Revision of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 - 37 T)

Adopted as Standard:

- Spec. for Concrete Aggregate (C 33 - 37 T)
- Spec. for Lightweight Aggregate for Concrete (C 130 - 37 T)
- Test for Coal and Lignite in Sand (C 123 - 36 T)
- Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 36 T)
- Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 36 T), with the following editorial change presented on the floor at the annual meeting:

  Section 2.—Change the requirement for calibration of the volumetric flask from "0.1 ml." to read "0.15 ml."
- Test for Sieve Analysis of Fine and Coarse Aggregates (C 136 - 38 T)
- Test for Yield of Concrete (C 138 - 38 T)
- Test for Clay Lumps in Aggregate (C 142 - 38 T)
- Terms Relating to Concrete and Concrete Aggregates (C 125 - 36 T), four definitions
- Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 38 T), as revised
- Test for Consistency of Portland-Cement Concrete (D 138 - 32 T), as revised
- Revisions of:
  - Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (C 87 -36)
  - Test for Unit Weight of Aggregate for Concrete (C 29 - 27)
  - Making and Storing Compression Test Specimens of Concrete in the Field (C 31 - 38)
  - Securing Specimens of Hardened Concrete from the Structure (C 42 - 31), except that the proposed addition of a new sentence in Section 6 was withdrawn by the committee
  - Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third Point Loading) (C 78 - 38)
  - Making Compression Tests of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method) (C 116 - 36)
  - Test for Flow of Portland-Cement Concrete by Use of the Flow Table (C 124 - 38)
- Revision of Method for Making Compression Tests of Concrete (C 39 - 33), with the following additional changes, not preprinted, accepted by unanimous consent, subject to favorable letter ballot of Committee C-9:[25]

Section 14.—Change from its present form to read as follows:

14. (*a*) Two to four hours after molding, the test specimens, if made in metal molds, may be capped with a thin cap of neat-cement paste. The cap shall be formed by means of a piece of plate glass ¼ in. in thickness or a machined metal plate ½ in. in thickness and of a diameter 2 or 3 in. larger than that of the mold. The plate shall be worked on the cement paste until the plate rests on top of the mold. The cement for capping should be mixed to a stiff paste 2 to 4 hr. before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the concrete to the top and bottom plates may be avoided by coating them with heavy oil or grease.

(*b*) If specimens are not capped with neat-cement paste, they shall be capped before testing in such a manner that the ends are perfectly plane and at right angles to the axis of the cylinder. The material used for capping and the thickness of the cap shall be such that it will not flow or fracture under the load.

NOTE.—It is desirable that the capping material have a value for modulus of elasticity equal to or greater than that of the concrete.

Publication as Information Only:

- Proposed Method of Test for Soundness of Aggregates by Use of Magnesium Sulfate
- Proposed Method of Test for Organic Impurities in Laboratory Washed Sand by pH Value

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[25] Committee C-9 reported results of the letter ballot vote as follows: Of a total membership of 68, 54 members returned their ballots, of whom 52 voted affirmatively, 1 negatively.

The following papers, appended to the report were presented:

A Statistical Analysis of Compression Tests on Mortar Cylinders, Cubes and Prisms—H. W. Leavitt and H. A. Pratt, presented by Mr. Leavitt.

Some Observations of the Water Vapor Permeability of Concrete—H. J. Barre, presented by W. M. Dunagan.

Methods for Measuring the Passage of Water Through Concrete—W. M. Dunagan, presented by the author.

Modified Procedure for Testing Concrete Aggregate Soundness by Use of Magnesium Sulfate—Charles E. Wuerpel, presented by title.

New Laboratory Method for Determining the Organic Matter in Fine Aggregates—Ira Paul, presented by the author.

Committee C-13 on Concrete Pipe:

Report presented, in the absence of the chairman, by E. F. Kelley, and the following action taken:

Adopted as Standard:

Spec. for Concrete Irrigation Pipe (C 118 – 38 T)

Papers:

The following papers were presented:

The Effect of Variations in Method upon the Results of Freezing and Thawing Mortars—Bert Myers, presented from manuscript by Stanton Walker.

Selection of Aggregates for Concrete Pavement Based on Service Records—Curtis Cantrill and Louis Campbell, presented by Mr. Cantrill.

The Effect of Biot's Modulus on Transient Thermal Stresses in Concrete Cylinders—Gerald Pickett; this paper, which has been presented at the Round-Table Discussion on Freezing-and-Thawing Tests, was submitted by title to provide additional time for discussion.

Thermal Volume Change and Elasticity of Aggregates and Their Effect on Concrete—T. F. Willis and M. E. De Reus, presented by Stanton Walker.

EIGHTEENTH SESSION—NON-FERROUS METALS, CHEMICAL ANALYSIS

Friday, June 30, 2 p.m.

Session Co-Chairmen: G. E. F. Lundell; J. R. Townsend.

Report of Committee B-1 on Copper and Copper-Alloy Wires for Electrical Conductors:

Report presented by W. H. Bassett, Jr., vice-chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Figure 8 and Figure 9 Deep-Section Grooved Copper Trolley Wire for Industrial Haulage, with the following editorial changes:

Title.—Change to read: "Spec. for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage.

Section 1 on Scope.—Change to read as follows:

These specifications cover figure 9, deep-section grooved, and figure 8 copper trolley wire for use in industrial haulage (Note 1).

Section 2.—Third paragraph, before "Lake Copper" add "low resistance."

Adopted as Standard:

Spec. for Hard-Drawn Copper Alloy Wires for Electrical Conductors (B 105 – 38 T), as revised

Spec. for Bare Stranded Copper Cable, Hard, Medium-Hard or Soft (B 8 – 38 T), as revised

Revision of Spec. for Hard-Drawn Copper Wire (B 1 – 38), with the following changes, not preprinted, accepted by unanimous consent, subject to favorable letter ballot of Committee B-1:[26]

Section 3 (c).—Change to read as follows by the omission of the material in brackets and addition of the italicized words:

(*c*) Wire whose nominal diameter *is more than 1 mil greater than a* [lies between] size listed in Table I shall conform to the requirements of the next larger size. [If the nominal diameter is more than 0.003 in. (3 mils) larger than a listed size whose diameter is 0.100 in. or over, and likewise if the nominal diameter is more than 0.002 in. (2 mils) larger than a listed size whose diameter is less than 0.100 in.]

Section 7.—Change to read as follows by addition of the italicized words and the omission of those in brackets:

7. *No joints shall be made in the completed wire.* [Necessary] Joints [in the completed

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[26] Committee B-1 reported results of the letter ballot vote as follows: Of a total membership of 30, 26 members returned their ballots, of whom 25 voted affirmatively, 0 negatively.

wire (Note 6) and] in the wire [and] *or* rods prior to final drawing shall be made in accordance with the best commercial practice (*Note 6*).

Note 6.—Delete the note as preprinted and replace with the following:

NOTE 6.—Mechanical joints made during inspection at the request of the purchaser are permissible if agreed upon at the time of placing the order.

Revision of Spec. for Medium Hard-Drawn Copper Wire (B 2 – 38), with the following changes, not preprinted, accepted by unanimous consent, subject to favorable letter ballot of Committee B-1:[26]

Section 3 (c).—Make the same change in this section as indicated for Section 3 (*c*) of Spec. B 1 given above.

Section 7 and Note 7.—Make the same change as indicated for Section 7 and Note 6 of Spec. B 1 given above.

Revisions of:
- Spec. for Soft or Annealed Copper Wire (B 3 – 38)
- Spec. for Tinned Soft or Annealed Copper Wire for Electrical Purposes (B 33 – 38)
- Spec. for Hot-Rolled Copper Rods for Wire Drawing (B 49 – 26)
- Spec. for Bronze Trolley Wire (B 9 – 38)
- Spec. for Copper Trolley Wire (B 47 – 38)

Withdrawal of Standard:

Spec. for Bare, Stranded Copper Cable, Hard, Medium-Hard, or Soft (B 8 – 36)

Committee B-2 on Non-Ferrous Metals and Alloys:

Report presented by E. E. Thum, secretary, and the following action taken:

Adopted as Standard:

Spec. for Rolled Zinc (B 69 – 37 T), to replace the present Standard B 69 – 29, this recommendation not having been preprinted was accepted by unanimous consent, subject to favorable letter ballot of Committee B-2.[27]

Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys:

Report presented by Dean Harvey, chairman, and the following actions taken:

Accepted as Tentative:

Testing Nickel and Nickel-Alloy Wire and Ribbon for Electronic Tube Filaments

Revision of Test for Flexivity of Thermoflex (Thermostatic Metals) (B 106 – 37 T)

Adopted as Standard:

Test for Temperature-Resistance Constants of Sheet Materials for Shunts and Precision Resistors (B 114 – 38 T)

Test for Linear Expansion of Metals (B 95 – 35 T), as revised

Revisions of:
- Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (B 70 – 30)
- Accelerated Life Test for Metallic Materials for Electrical Heating (B 76 – 38)
- Spec. for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical Heating Elements (B 82 – 34)
- Spec. for Drawn or Rolled Alloy, 60 per cent Nickel, 15 per cent Chromium, and Balance Iron, for Electrical Heating Elements (B 83 – 34)

The recommendation for adoption as standard of the Tentative Method of Bend Testing of Wire (Wire for Radio Tubes and Incandescent Lamps) (B 113 – 38 T) was withdrawn from the report by the committee, the method to be continued as tentative.

Committee B-5 on Copper and Copper Alloys, Cast and Wrought:

Report presented by C. H. Greenall, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Leaded Brass Sheet and Strip

Spec. for Copper-Nickel and Copper-Nickel-Zinc Alloy Sheet and Strip

Classification of Cast Copper-Base Alloys

Spec. for Beryllium-Copper Bars, Rods, Sheet, Strip, and Wire, with the following additional changes, not preprinted, accepted by unanimous consent, subject to favorable letter ballot of Committee B-5:[28]

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[27] Committee B-2 reported results of the letter ballot vote as follows: Of a total voting membership of 97, 72 members returned their ballots, of whom 40 voted affirmatively, 0 negatively.

[28] Committee B-5 reported results of the letter ballot vote as follows: Of a total membership of 74, 57 members returned their ballots, of whom 38 voted affirmatively, 0 negatively.

Section 1.—Add the word "alloy" after the words "beryllium-copper."

Section 2 (a).—Add the word "process" after the words "cold working."

Section 3 (a).—After "3 hr." add the words "or by an equivalent process."

Section 3 (b).—Change from the form as preprinted, to read as follows, by the addition of the material in italics and the omission of the material in brackets:

(*b*) The material shall be heat treated[a] by heating at 250 to *350* [300] C. (482 to *662* [572] F.) for up to 3 hr. The exact time and temperature shall be regulated to conform to the physical requirements prescribed in Section 7 [and 8,] and Tables II, III and IV [V].

Section 4.—In the table under section 4, change the second and third items to read as follows by the addition of the italicized words and the omission of those in brackets:

Other additive elements employed to obtain special properties [Metals employed as grain growth inhibitors (such as nickel)], max., per cent.......................... 0.50

Elements [Other metals] (impurities) *other than above*, max., per cent.. 0.50

Section 8.—Delete this section, renumbering the subsequent sections accordingly.

Table III.—Delete this table, and renumber the subsequent tables accordingly.

Section 9.—Add an introductory sentence to this section, reading as follows:

The number of hardness tests shall be not less than three on each of the representative samples described in Paragraphs (*a*) and (*b*).

Omit Paragraph (*c*) from Section 9.

Table IV.—Under the heading Elongation in 2 in., change the last two items from "10.0" and "3.5" per cent to read "3.0" and "2.0" per cent, min., respectively.

Table V.—Under the heading Tensile Strength, psi., change the requirement for wire in the ½ HT condition from "180 000" to read "175 000" psi., min.

Under the heading Elongation in 2 in., change the second, fourth and sixth items from "5," "3" and "1.5," per cent, min., to read "1.5," "1.0," and "0.5," per cent, min., respectively.

Spec. for Copper-Base Alloy Forging Rods; with the addition to the title and text of the specifications of the words "Bars and Shapes."

Spec. for Nickel-Silver Alloys (Nickel-Brass) in Ingot Form for Sand Castings, with the following additional changes:

Title: Change to read "Spec. for Leaded-Nickel-Brass and Leaded-Nickel-Bronze (Nickel-Silver) Alloys in Ingot Form for Sand Castings."

Section 4 (b).—Change the word "may" to "shall."

Table I.—After the heading Zinc, add a footnote *a* to read as follows:

[a] Zinc may be taken as remainder provided copper is determined.

Under the heading Other Elements, max., per cent, delete the values for Aluminum and insert the word "none" with a footnote *b*, reading as follows:

[b] None is defined as less than 0.005 per cent as determined by A.S.T.M. Tentative Methods of Chemical Analysis of Brass Ingots and Sand Castings (B 45 - 36 T).

Appendix.—In the first table in the appendix, under the heading Alloy, add the names for the alloy numbers as follows: Leaded-nickel brass, for Nos. 1 and 2; Leaded-nickel bronze and brass, for No. 3; and Leaded-nickel bronze, for No. 4. Add the following footnote to the leaded-nickel bronze and brass:

[b] This alloy is termed leaded-nickel brass if zinc is above 10 per cent, and leaded-nickel bronze if zinc is below 10 per cent.

Revisions of:
- Spec. for Sheet and Strip Phosphor Bronze (B 103 - 36 T)
- Spec. for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 38 T)
- Spec. for Manganese-Bronze Ingots for Sand Castings (B 7 - 27)
- Spec. for Manganese-Bronze Sand Castings (B 54 - 27)

Adopted as Standard:

Spec. for Sheet Copper-Silicon Alloy (B 97 - 36 T)

Spec. for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 - 36 T)

Spec. for Copper-Silicon Alloy Wire for General Purposes (B 99 - 37 T)

Revisions of:
- Spec. for Copper Water Tube (B 88 - 33)
- Spec. for Manganese-Bronze Ingots for Sand Castings (B 7 - 27)
- Spec. for Manganese-Bronze Sand Castings (B 54 - 27)

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[a] *Heat treatment must be carried out subsequent to soft annealing. It may be carried out after soft annealing and cold working where higher strengths are desired.*

Spec. for Aluminum-Bronze Castings (B 59 – 38)

Reversion of Standards to Tentative:

Spec. for Copper Pipe, Standard Sizes (B 42 – 33), as revised
Spec. for Seamless Copper Tubing, Bright Annealed (B 68 – 33), as revised
Spec. for Brass Pipe, Standard Sizes (B 43 – 33), as revised.

Withdrawal of Standard:

Spec. for Brass Forging Rod (B 15 – 18)

The committee withdrew from its report as preprinted the recommendation for withdrawal of the Standard Specs. for Copper Bars for Locomotive Staybolts (B 12 – 33), and for Seamless Brass Boiler Tubes (B 14 – 18).

The committee also withdrew from its report the recommendation for the adoption as standard of the Tentative Specifications for Copper-Silicon Alloy Plates and Sheets (B 96 – 36 T), and it was announced that revisions in these specifications would be presented to the Society through Committee E-10 on Standards, subsequent to the annual meeting.

The following papers, appended to the report, were presented by the authors:

Nomenclature and Classification of Cast Copper and Copper-Base Alloys—Sam Tour.

Service and Life of Non-Ferrous Tubes in Petroleum Refining[29]—E. S. Dixon.

Committee B-6 on Die-Cast Metals and Alloys:

Report presented by J. R. Townsend, chairman, and the following actions taken:

Accepted as Tentative:

Revisions of:

Spec. for Lead and Tin-Base Alloy Die Castings (B 102 – 35 T)
Spec. for Aluminum-Base Alloy Die Castings (B 85 – 37 T)
Spec. for Magnesium-Base Alloy Die Castings (B 94 – 37 T)

A paper on "Magnesium Alloy Die Castings," by A. W. Winston, to be appended to the report, was presented from manuscript by the author.

Committee B-7 on Light Metals and Alloys, Cast and Wrought:

Report presented by Sam Tour, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Aluminum-Base Alloys in Ingot Form for Die Castings
Spec. for Aluminum Alloy Ingots for Remelting (B 24 – 39 T)
Spec. for Aluminum for Use in Iron and Steel Manufacture (B 37 – 39 T)
Revisions of:
  Spec. for Aluminum-Alloy (Duralumin) Sheet and Plate (B 78 – 36 T)
  Spec. for Aluminum-Alloy (Duralumin) Bars, Rods, and Shapes (B 89 – 36 T)
  Spec. for Magnesium-Base Alloy Ingot for Remelting (B 93 – 38 T)
  Spec. for Aluminum-Magnesium-Chromium Alloy Sheet and Plate (B 109 – 36 T)

Adopted as Standard:

Magnesium Ingot and Stick for Remelting (B 92 – 36 T)

Withdrawal of Standards:

Spec. for Aluminum Ingots for Remelting (B 24 – 29)
Spec. for Aluminum for Use in the Manufacture of Iron and Steel (B 37 – 26)

Committee E-2 on Spectrographic Analysis:

Report presented by H. V. Churchill, chairman.

Committee E-3 on Chemical Analysis of Metals:

Report presented by G. E. F. Lundell, chairman, and the following action taken:

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[29] Published in ASTM BULLETIN, No. 102, January, 1940, p. 21.

Adopted as Standard:

Methods of Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron (E 30 - 36 T)

Papers:

The following papers were presented:

Spectral Emissivity (at 0.65 μ) of Some Alloys for Electrical Heating Elements—W. F. Roeser, presented by title by the author.

The Determination of Silicon in Certain Aluminum Alloys Containing Silicides—T. A. Wright and John Jicha, presented from manuscript by Mr. Wright.

The Spectrographic Analysis of Tin—J. Warren Stewart, presented by the author.

There being no further business, the chairman then declared the Forty-second Annual Meeting adjourned *sine die.*

GLIMPSES AT PETROLEUM

ANNUAL ADDRESS BY THE PRESIDENT

T. G. DELBRIDGE[1]

June 27, 1939

You will readily appreciate the doubt, hesitation, and no small degree of humility with which a President of the American Society for Testing Materials approaches the privilege and duty of preparing a paper to go into our Society archives as a Presidential Address. It may not be unseemly this year to devote a part of our time to petroleum, a material that is of very great present importance to A.S.T.M. It is of even greater importance to your President personally than it is to the Society. Its importance to each of you, personally, is probably greater than you perceive. If this presentation is of some slight interest, if it adds a bit to your individual knowledge, and particularly if it stimulates a somewhat greater realization of civilization's reliance on petroleum, then its purpose will have been served. Because of the many aspects of petroleum, and particularly because your time and probably your patience are not unlimited, it is hoped that the title, "Glimpses at Petroleum," will be followed literally enough to encourage your attention.

Crude petroleum, frequently called "crude oil" or just "crude," is a natural mineral product. The A.S.T.M. definition states that it is: "A naturally occurring mixture, consisting predominantly of hydrocarbons, and/or of sulfur, nitrogen and/or oxygen derivatives of hydrocarbons, which is removed from the earth in liquid state or is capable of being so removed." As to occurrence, crude petroleum is found in many countries, though the United States still produces more than half of the world total. It occurs at various depths below the surface, ranging from surface seepage to many thousands of feet. In the A.S.T.M. definition, the word "mixture" is truly deserving of italics, if not capital letters. Not only do most crude petroleums contain literally thousands of individual chemical compounds, but there is a tremendous variation in the proportions of these compounds. One crude oil may contain hundreds of compounds, found not at all or only in traces in another. As a result, crude oils vary widely in physical and chemical properties. For example, the color of crude petroleum ranges from practically colorless, through yellow, orange and red to a brown so dark as to appear practically black. In specific gravity, the range is from heavier than water to a specific gravity only two-thirds that of water. In consistency, the variations are from a fluid thinner than water to a semiplastic solid. Thus our first glimpse at petroleum makes it clear that the name crude petroleum is generic and that each crude oil has somewhat the same individuality as a tree or a vegetable.

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[1] Manager, Research and Development Dept., The Atlantic Refining Co., Philadelphia, Pa.

Having at least some idea of what crude petroleum is, it is of interest to inquire whence it came and when. While many different theories have been advanced as to its origin, the one most generally favored is that petroleum has come from a slow chemical transformation of marine organic matter deposited as sediments on the muddy bottoms of salt seas that existed millions of years ago. In general, petroleum is produced from sedimentary rocks and from those which, while old in years, are comparatively young from the viewpoint of the geologist. It concerns us but little whether this slow evolution of petroleum began eighty million years ago or a hundred million. Nature's laboratory has produced a marvelous product, marvelous not only in composition and varieties but possibly most of all in the slowness with which these many crude petroleums came into being. In passing, we may note that coal is probably derived in a somewhat similar way from vegetation gradually engulfed in the fresh water of inland seas of bygone ages.

Perhaps we should now take a glimpse at petroleum as to its age in human hands. When it was first found and used by man is not known, but references to it are at least thousands of years old. Quantities appear to have been negligible and the uses were weird, including medicinal ones. Around 1800, the slight film of petroleum floating on Oil Creek in western Pennsylvania was recovered by carefully laying blankets on the surface until the oil had been absorbed, then wringing them. Sold as a panacea for human ills, this crude oil was doubtless just about as effective as a rabbit's foot or a bag of asafetida. In 1859, near Titusville, Pa., Col. E. L. Drake drilled his famous well. At 69 ft. he struck oil. This Drake well produced about 20 barrels per day for a short time. Other wells were drilled promptly and in 1860 the country's production was estimated at half a million barrels per day. A new industry had been born. It started to grow at a phenomenal rate. New problems were in the making for the explorer, for the driller, the chemist, the engineer, for the merchant and the banker, and for the American Society for Testing Materials. So while petroleum goes back to the ichthyosaurus geologically, and back to Noah or Herodotus historically, it became an engineering material and the basis of a mighty industry only eighty years ago.

The old saying goes, "Oil is where you find it." To find oil as a seepage from the earth's surface is easy, if there is such a seepage. To find oil a hundred feet below the earth's surface is not easy. To find it miles below the surface is a colossal task. Even in early days, geologists were frequently employed to search for petroleum. They had active competition from the numerous individuals who employed "divining rods" and other magic. The story of these magic devices and methods for finding oil is interesting reading, interesting not only on account of their absurdity but on account of their variety and the ingenuity of some of the mechanical contrivances. Probably perpetual motion machines and "oil finders" will continue to occupy the attention of cranks as long as man survives. The only magic that has ever led to finding petroleum is that magic which is the product of science, planned and at least partially understood. No procedure is known today which actually locates oil. Possibly no such method will ever exist. There are methods, however, which are fairly successful in locating sub-surface rock structures of a kind which experience has shown may carry petroleum. Today hundreds of scientists are applying known principles of geology, physics, chemistry, paleontology and other sciences to this art of locating favorable rock structures. In taking this glimpse at petroleum, it is important to remember that oil may be only a few hundred feet below the surface but is usually more than a mile down. Thus you will appreciate some of the difficulties. Among the methods employed in locating favorable sub-surface rock formations are those which measure density differences as determined by the torsion balance, magnetic properties, and behavior toward electricity and toward seismic vibrations. From the venerable science of earthquakes, a new seismology has been developed by geophysicists seeking oil. In the early days of seismographic exploration it was not uncommon to explode a charge of several hundred pounds of dynamite to generate a seismic wave. Today, with instruments of greater sensitivity and with better technique, a few pounds of dynamite properly placed and exploded make it possible to survey seismographically over a five-mile surface range and to a depth of somewhat over one mile.

In spite of all the scientific progress made in methods of exploration for petroleum, there is only one man who can prove that oil exists at a certain depth below any surface locality. That man is not the geologist, nor the paleontologist, nor the geophysicist. In fact he is not a scientist at all but an artist—the driller—who practices one of the most difficult of all arts. Drilling is the only known test for the presence of oil. It is no exaggeration to refer to the driller as a fine artist. Picture to yourself an oil derrick in a prairie or in a swamp or even over the ocean. From this derrick a hole is drilled into the earth, and from time to time the drill is removed and the hole cased with special pipe to keep it open. Drilling is continued, most of it through solid rock. Day after day and week after week the drill goes down until, perhaps two miles below the surface, oil is struck or the well is given up as a dry hole. The deep well of 1938 was 15,000 ft. deep—nearly 3 miles. When oil is struck—and particularly at great depths—it is usually under tremendous pressure, say 5000 lb. per sq. in. Such pressure, in spite of precautions and safeguards, is sometimes enough to blow drill and casing out of the well like a projectile fired from a mighty gun. When this happens lucky oil becomes a catastrophe, for when an oil well blows out, the oil usually takes fire. To extinguish a flaming torch hundreds of feet high and burning thousands of gallons of crude oil per minute is another one of the petroleum industry's numerous gigantic problems—gigantic in hazard, in cost and in demand for promptness, ingenuity and patience.

Examining another aspect of drilling, suppose two oil wells are started at the surface several hundred feet apart. The drills go straight down or almost straight down for a few hundred feet. Then suppose one of them is deflected slightly by an unusually hard rock formation. Perhaps a few thousand feet below the surface, the two drills meet and tangle. Not even the Greeks had a name for such a mixup. The problem of drilling straight down became more important as well depths increased. Again science made its contributions, and today wells can be drilled practically straight with the help of instruments which record deviation from the vertical with remarkable accuracy. We now know how to drill straight holes, even three miles deep. We do not know how to avoid drilling dry holes—and dry holes cost as much to drill as gushers. Of all the wells drilled in the United States during recent years, about 25 per cent have been dry holes. Because most wells are put down in proven territory, a better idea of the odds against striking oil by drilling in new regions is given by the statement that in 1937 over 80 per cent of such wildcat wells were failures.

In our next glimpse at petroleum, we shall assume that at large cost we have prospected for oil, that we have purchased or leased the necessary land, that we have drilled two miles into the earth and in spite of all the probabilities against us we have actually struck oil and have succeeded in controlling its flow without fire or other disaster. Crude oil in a swamp or other wilderness is scarcely more useful than it was ten thousand feet below the surface. To become useful it must be transported to a refinery. Thus, with crude petroleum at the well, we are only at the start of a journey. Oil transportation by modern methods developed by the petroleum industry is a major factor in the great reduction in price of petroleum products. Oil pipe lines in the United States have a total length well over 100,000 miles; for water transportation, vessels are in use of varying sizes up to a capacity of 165,000 barrels. The most modern tankers of this enormous size can be loaded or discharged in less than 24 hr. at a rate of one thousand tons per hour.

The storage of petroleum at the well, at the point of delivery to the carrier, and at the destination is in itself a huge task. The many hazards of handling an inflammable liquid have been reduced to an almost negligible point by modern developments which have at the same time greatly reduced the earlier substantial loss by evaporation of gasoline, the volatile component of petroleum. Tanks with floating roofs, with collapsible roofs, with breather balloons, with insulation against sun heat, with pressure and vacuum relief valves, flame arresters and automatic gaging devices—all these are only part of the developments applied by the engineer to oil storage problems.

With the crude petroleum found, produced, and transported to a refinery, it is still only crude petroleum and not fit for any use—except perhaps for killing the larvae of mosquitoes. It will not even grow human hair, in spite of a not inconsiderable use for that purpose by a trusting public—possibly including yourself. Distillation has been and still is the most important single refining process applied to petroleum. From the early batch stills charging only a few barrels and later a few hundred barrels of crude petroleum, the industry now operates continuous distillation units in which the oil is heated to suitable high temperature while being pumped at high velocity through pipe coils arranged in huge furnaces. The mixture of vaporized and unvaporized oil is passed into fractionating towers of complicated design, construction, and operation with heat exchangers, coolers, condensers, control instruments, and safety devices. One such so-called pipe still usually processes five thousand barrels of crude oil daily and often the capacity is several times this figure. This primary distillation continuously splits the crude oil into the stocks from which are made, respectively, gasoline, kerosine, lubricating oil, wax, asphalt, and the many other forms of refined petroleum so intimately associated with our modern way of living. The subsequent steps in refining are varied, depending on the nature of the crude oil, the product specifications to be met, and to some extent on the refiner's preference.

At this point, it is desirable to focus your attention on a development outside the petroleum industry which has had a profound effect on its growth and on its rate of growth. That development was the horseless carriage. At the end of the last century, the horseless carriage was beginning to get out of the museum class and to creep out on the highways and even to creep along the highways. These somewhat grotesque vehicles required petroleum: as gasoline, as lubricating oil, as grease and other lubricants. Without petroleum, no horseless carriage—at least not in motion. But the horseless carriage captured the American public—it became an automobile—it gained in looks, in speed, in dependability. It put a real drain on the gasoline available from petroleum. During and following the World War, aviation also put a further demand on petroleum for gasoline and for lubricants. The American petroleum industry was not found lacking in courage, research, engineering, nor in the tremendous financial investment necessary to keep automobiles running on the ground, motor launches operating on water, and to keep airplanes in the air. In the last twenty-five years, we have learned how to convert into gasoline by chemical methods enough of crude petroleum to supply twice as much gasoline per barrel of crude oil as is contained in the oil itself. This fact, coupled with the better fuel quality of today's gasoline, means that approximately twice as much crude petroleum would be required for the production of today's gasoline requirements had not science and engineering developed the numerous processes for transforming into gasoline the practically nonvolatile fractions of crude petroleum. It is an opportune time to say to you that the petroleum industry could not have kept your automobiles running had it not been for the ferrous and other metal alloys developed by engineers and metallurgists, many of whom have been active in the American Society for Testing Materials.

While the petroleum industry has made enormous improvements in its various branches during the last quarter century, improvements which have made better and better products at lower and lower selling price, it has throughout that period recognized the profitability of employing competent workers and paying them well. As a typical example, the U. S. Department of Labor reports that in December, 1938, those engaged in the production and refining of crude petroleum received an average hourly rate of pay almost 50 per cent higher than the average for all manufacturing industries. This not only explains why we have many oilmen with forty and even fifty years of active service, but it is a considerable factor in maintaining efficient operation, in the rapid adaptation to new apparatus and new processes, and, most important of all from the humanitarian angle, in the safety consciousness of the workman, for himself and for his fellow workers.

Another vital factor in the constant extension of better petroleum products at lower prices is the increasing attention and support given to research. In addition to their own laboratories and research staffs, many of the oil companies support specific research projects at our universities and employ as consultants some of the most eminent scientists and engineers in our land. Cooperation with other industries in research on problems of mutual interest has been found highly profitable. A number of these cooperative projects have been with A.S.T.M. participation.

To some of us it seems highly probable that research in all branches of the petroleum industry will become increasingly important to keep step with the continuing increase in better performance requirements imposed on practically every petroleum product marketed today.

In these various glimpses at petroleum, it is hoped that the absence of statistics has been recognized and possibly appreciated. If any of you desire statistics, it will be a pleasure to give suitable references on request. On this occasion, however, you will perhaps be receptive to two statistical statements relating to gasoline in the United States and comparative between 1938 and 1923, fifteen years earlier. First, excluding tax, the average retail price per gallon in 1923 was 50 per cent higher than in 1938. Second, in spite of the enormous increase in the gasoline sales tax, the average price of gasoline, including the tax, is about two cents a gallon less than it was fifteen years ago.

Some idea as to how long our petroleum reserves are likely to last is our next glimpse at petroleum—and in this case the word "glimpse" is peculiarly appropriate. Obviously no specific answer can be given to the question. During his thirty years work in petroleum, your President has seen successive estimates, many of them indicating that the exhaustion of our petroleum was not remote. If the 1908 estimate had been correct, we would have no petroleum today. If the 1918 estimate had been correct, this country's petroleum would have been exhausted about nine years ago. The 1939 estimate of proven reserves is about 17 billion barrels and at the consumption rate of 1938 this proven reserve alone would last only fourteen years. But advanced methods of exploration, of drilling, and of recovery have been and are not only increasing the proven reserve but they are opening up almost unsuspected possibilities in future reserves not yet proven. In 1909 a deep well was 6000 ft., in 1929 it was 9000; in 1938, 15,000 ft. Not only is there an increase in the proportion of oil recovered from a given field, but new methods are being applied whereby old fields that were thought to be exhausted are again producing. In one Pennsylvania field, for example, water drive methods have demonstrated a reserve that is greater than all the oil taken out of that field in the past seventy years. If you must have an answer to the question "How long?", perhaps 150 years is none too high. Therefore, if any of you have sons or grandsons or daughters or great-granddaughters who want to enter the petroleum industry, it probably offers a more permanent outlet for hard work and keen competition than almost any business other than food and politics.

The American petroleum industry is of considerable importance to the American Society for Testing Materials for several reasons. As consumer, the producing, refining, transportation, and marketing branches are purchasers of large quantities of metal, both ferrous and non-ferrous; of cement, timber, and paint; of rubber, textiles, and electrical supplies. In fact all branches of the industry are sizeable consumers of nearly all the materials now within the scope of A.S.T.M., including both soap and water for industrial purposes. Therefore, the petroleum industry not only requires and uses A.S.T.M. Standards with respect to these materials of which it is a consumer, but it cooperates substantially in the formulation of standards for such materials. Furthermore, as a producer, the petroleum industry manufactures products which are somewhat unique with A.S.T.M. in that many of them are of direct personal interest to the individual consumer. There are doubtless many of you who have never bought a pound of silicon steel nor even one bag of portland cement. Presumably, nearly every one of you buys gasoline and various petroleum lubricants, while statistics show that you are buying an increasing amount of furnace oil. Through petroleum products, therefore, the Society has a very direct contact with the private individual as well as the large industrial user. Another way in which the petroleum industry has shown its very sincere interest in the American Society for Testing Materials is in at least average participation in the work of our administrative committees.

However, as a concluding glimpse at petroleum, it is your President's opinion, without reservation of any kind, that the petroleum industry is indebted to A.S.T.M. far in excess of such services as it has performed for A.S.T.M. The Society has been the forum in which petroleum men as producers could discuss broad and specific problems with consumers. The Society has been the medium through which it has been possible to standardize many test methods for petroleum products including gasoline, kerosine, lubricants, fuel oils, asphalts, waxes, paint thinners, and insulating materials. The Society has again and again been the coordinator of research, of argument, of experimentation and of collaboration that has led to practically universal benefit to the ultimate consumer. A specific case will well illustrate such a benefit.

Some years ago numerous automobile drivers complained of difficulty in starting their motors on cold mornings. Investigation of these complaints showed that the explanation lay, not in gasoline quality, but in the facts that winter driving was increasing and that engine clearances had been reduced. Earlier studies had shown that lowering the viscosity of the oil in the crankcase gave satisfactory starting at lower temperatures. Accordingly, the motor manufacturers promptly revised their recommendations as to the viscosity of motor oil for cold weather driving. While this reduced the number of complaints, it did not eliminate them. Further study indicated that the Saybolt method of measuring viscosity was not accurate enough to predict whether at low temperature, such as 0 F., a given oil would be fluid enough to permit easy starting and yet viscous enough to lubricate safely after the motor had reached operating temperature. The Society of Automotive Engineers then requested A.S.T.M. to develop a more accurate method. As a result, kinematic viscosimeters of the capillary tube type have been standardized and the results are so accurate and reproducible that the oil refiner can now predict, with full confidence, the behavior of his lubricating oils when used even at extremely low temperatures. The great importance of this A.S.T.M. contribution to the oil industry and to the public is evident. Other examples of our Society's benefits to the petroleum industry are numerous, such as substitution of relatively simple laboratory examinations for expensive and time-consuming engine tests for various qualities in gasoline, including permissible vapor pressure, starting, gum stability, and others.

It is hoped that these glimpses at petroleum may have been of interest to some of you and that to all of you it will be evident that the petroleum industry is courageous, progressive, keenly alert to the value of "the promotion of knowledge of the materials of engineering and the standardization of specifications and the methods of testing" and therefore deeply indebted to the American Society for Testing Materials.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE

The Executive Committee offers the following report on general Society activities for the year ending with this annual meeting:

Membership:

The membership of the Society on June 1, 1939, was 4199. Statistics showing gains and losses in the various classes of membership are as follows:

Class of Membership	Membership		Losses				Additions		Total		
	June 1, 1938	June 1, 1939	Resignations	Dropped	Death	Transfer	Transfer	Election	Loss	Gain	Increase
Honorary	3	6	...	...	...	...	3	....	...	3	3
Life or Perpetuity	10	10	...	...	...	...	....	....	...	...	...
Sustaining	12	21	...	...	...	...	9	....	...	9	9
Company, Firm, etc.	1016	1022	34	8	...	12	7	53	54	60	6
Individual, etc.	3062	3090	141	43	25	11	16	232	220	248	28
Junior	53	50	6	3	...	12	....	18	21	18	3[a]
Total	4156	4199	181	54	25	35	35	303	295	338	43
Student	331	356	33	137	...	9	....	204	179	204	25

[a] Loss.

The net gain for the year of 43 compares with 164 for the preceding year and 251 for two years ago. Losses from resignations and delinquencies are higher and elections to membership lower than for the preceding year, which is probably a direct reflection of adverse industrial conditions. The number of student members increased from 331 to 356.

It is gratifying to report substantial increase in the number of Sustaining Members, from 12 to 21. The following nine sustaining memberships have been acquired since the first of the year by transfer of an existing company or individual membership, the names being listed in the order of acquiring membership:

The International Nickel Co., Inc.
The B. F. Goodrich Co.
Aluminum Co. of America
The Detroit Edison Co.
Bakelite Corp.
Vanadium Corporation of America
Phillips Petroleum Co.
General Electric Co., Schenectady Works
United States Gypsum Co.

A number of companies are giving thoughtful consideration to this form of membership, representing as it does increased financial support of the Society's activities, and the Executive Committee is encouraged in the belief that a further substantial increase in sustaining membership will come about. Assurance of sympathetic interest has been given by a number of other companies who are only awaiting favorable industrial conditions to become sustaining members.

Three honorary members were elected at the annual meeting last year, namely, Frank O. Clements, William K. Hatt and Herbert F. Moore. There are now six honorary members of the Society.

At the annual meeting last year certificates commemorating forty years of continuous membership from 1898 were awarded to the following nine individual and five company members:

Frank A. Barbour
Allan W. Dow
William K. Hatt
Alexander Jarecki
Andrew Lundteigen
William Mueser
Alvah Horton Sabin
Albert Sauveur
Arthur N. Talbot
American Foundrymen's Association
Bethlehem Steel Co.
Booth, Garrett & Blair
Carnegie Steel Co.
Franklin Institute

Similar certificates will be awarded at this annual meeting to the following who have been members continuously since 1899:

W. H. Broadhurst
Frank G. Kennedy, Jr.
Robert W. Hunt Co.
The Lowe Brothers Co.

The Executive Committee wishes to express its appreciation to the many members of the Society and to the several district committees who have given their help and cooperation in the important work of building up Society membership. Present industrial conditions make it all the more necessary to carry this work forward with unabated vigor.

The Society has lost the following members through death:

	Date of Membership
Balcom, H. G.	1920
Baxter, George L.	1930
Bergquist, J. G.	1904
Bolton, Edward John	1938
Dingle, James H.	1931
Gilmore, Grant K.	1929
Green, G. A.	1922
Jennison, H. C.	1909
Kenney, Frederick	1936
Koch, C. S.	1936
Lovell, Alfred	1908
Luss, Henry J.	1924
McCulloch, John A.	1909
Monk, Grant	1921
Murray, C. B.	1904
Revere, Guilio	1923
Rogers, Allen	1910
Sauveur, Albert	1896
Seley, C. A.	1936
Shimer, Porter W.	1899
Sullivan, Vernon L.	1928
Tavener, L. J.	1932
Taylor, H. G.	1916
Withers, Elmer G.	1936
Wohrman, Carl R.	1932
Young, J. B.	1907

Many of these members were engaged in the technical or administrative work of the Society, among them, H. C. Jennison, Frederick Kenney, Grant Monk, C. B. Murray, Allen Rogers, Albert Sauveur, and J. B. Young. Doctor Rogers had shortly before his death been elected to membership on the Executive Committee. Doctor Sauveur had been a member since the very inception of the Society and was the Edgar Marburg Lecturer last year. Mr. Young had been chairman of Committee A-1 on Steel and A-2 on Wrought Iron, and had served on the Executive Committee.

Committee Activities:

The work of the committees during the past year, as recorded in their annual reports to the Society at this meeting, has been unusually productive. The committees have reviewed their standards and tentative standards to bring them up to date, and to see that tentative standards and tentative revisions of standards are considered for adoption as standard. Furthermore, the resetting of all standards in the new double-column format, referred to later in this report, has required consideration by the committees of many editorial questions, which frequently have led to revisions that are being proposed for immediate adoption at this meeting. Several of the newer committees are presenting substantial reports this year.

Throughout all this committee activity, there is seen a continual and apparently growing demand from industry for more knowledge of properties of materials and for the recording of such knowledge in methods of test and specifications. This is of course gratifying and indicative of the great need for the kind of work the Society is doing. At the same time, it places a great responsibility upon the Society and its committees to see that our research activities are carried out thoroughly, that our standards are based upon the best and fullest knowledge obtainable, and that the greatest care is exercised by the committees to see that all sides of a question at issue are fully considered and all parties having a proper interest have opportunity to be heard. The very fact that A.S.T.M. standards are so widely accepted as authoritative makes this responsibility all the greater.

The current reports of Committees E-9 on Research and E-10 on Standards deal with certain phases of the committee work and, supplemented by reviews that will appear in the August and October issues of the ASTM BULLETIN, give a general summary of the committee activities.

The organization in recent years of three new committees, namely, C-14 on Glass and Glass Products, D-6 on Paper and Paper Products, and D-20 on Plastics, has raised certain questions of jurisdiction in relation to the work of Committee D-9 on Electrical Insulating Materials, which has long been engaged in development of tests for glass, paper, and plastics in their use for electrical insulation. Committee D-9's work in the field of glass has been largely confined to glass insulators, and the development of standards for that product has been assigned to Committee D-9; furthermore, in order that the committee may keep in touch with the more general studies of glass by Committee C-14, it has been arranged that D-9 be represented officially upon C-14.

Committee D-9 has written various tests for electrical insulation paper, some of which are of general application and will be of interest to Committee D-6 as its work on general paper testing methods is developed. Accordingly, formal representation of each committee upon the other has been arranged, with the understanding that electrical tests will continue to be written by Committee D-9 and that the two committees will cooperate in the development of general tests that may apply to insulating paper.

The situation with respect to plastics is somewhat more involved because of the extensive use of plastics in electrical insulation and the large amount of work that Committee D-9 has done in this field. A joint meeting of the advisory committees of Committees D-9 and D-20 has served to define the problem of coordination in its various aspects. It appears desirable for Committee D-9 to continue its work on plastics, both as to electrical as well as other tests, but with respect to the latter to keep in touch with Committee D-20's work in the general field. Arrangements have been made for exchange of minutes of meetings between the officers and subcommittee chairmen of the two committees; formal cross-representation is thought to be unnecessary in view of the existing duplication in membership. Nevertheless, on specific projects formal representation may be arranged; such arrangement has already been made to facilitate cooperative work on temperature and humidity control in testing.

A joint advisory committee consisting of two representatives from each of Committees C-8 on Refractories and C-16 on Thermal Insulating Materials was formed to facilitate coordination of the activities of the two committees.

On the recommendation of Committee E-10 on Standards, the Executive Committee has authorized the formation of a new standing committee on Sulfur Cements. The use of this material is increasing and need has been expressed by both producers and users for standard tests and specifications for the product. Municipalities and other large users of sulfur cements as pipe jointing materials are faced with the problem of writing specifications and it appears that the Society might perform a valuable service in undertaking the development of standards. It is hoped to organize the committee next fall.

Committee C-9 on Concrete and Concrete Aggregates has with the approval of the Executive Committee established the Sanford E. Thompson Award, as an annual token of recognition to the author or authors of a paper of outstanding merit on concrete and concrete aggregates presented at an annual meeting of the Society. The award is named in honor of the first chairman of the committee. The purposes are to stimulate research, encourage the presentation of results of investigations that extend the knowledge of concrete and concrete aggregates, and to recognize meritorious efforts. The award is $50 with a suitable certificate, funds for the award having been provided by Committee C-9. The committee on award will consist of three members of Committee C-9 appointed by its Advisory Committee. It is intended that the award be made annually unless in the opinion of the committee on award there is no paper in a given year worthy of the honor. The award will be made at a session on Concrete during the annual meeting of the Society following that at which the paper was presented. The Executive Committee commends and thanks Committee C-9 for the establishment of this award.

Administrative Regulations:

The following revisions of Articles III and IV of the Regulations Governing Standing Committees have been agreed upon jointly by the Executive Committee and Committee E-5 on Standing Committees and are here announced to become effective September 15, 1939, with the understanding that all changes involving amendment of the By-laws as noted later in this report will require approval by letter ballot vote of the Society. Committee E-10 on Standards has cooperated most effectively in developing these revisions of the Regulations, having done much of the actual work of rewriting.

Article III. Standards and Recommended Practice.—Change from its present form to read as follows:

> 10. Standards.—The term "Standards" shall be applied collectively to standard specifications,[a] standard methods,[a] and standard definitions that have been approved by the sponsoring committee and adopted by the Society in accordance with the procedure established therefor (Sections 14 and 15).
>
> 11. Tentative Standards.—The term "Tentative Standards" shall be applied to those specifications, methods, and definitions that have been approved by the sponsoring committee and accepted by the Society in accordance with the procedure established therefor (Sections 14 and 15), for publication and use preliminary to adoption as standard, thus providing opportunity for suggestion and criticism.
>
> 12. Recommended Practices.—The term "Recommended Practices" shall be applied to processes and methods not ordinarily subject to contract between purchaser and manufacturer.
>
> 13. Nature of Committee Recommendations Regarding Standards.—Recommendations of standing committees regarding standards may cover:

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[a] Specifications are designed to govern the purchase of materials in terms of physical, chemical, or other properties. Methods include sampling and test procedures used in determining the properties that may be specified but not values for these properties.

(*a*) Adoption as standard (immediate adoption or adoption after publication as tentative), revision of standard (immediate adoption or adoption after publication of revision as tentative), tentative revision of standard.

(*b*) Acceptance of tentative standard, revision of tentative standard.

(*c*) Publication of draft of proposed standard as information.

(*d*) Withdrawal of standards, tentative standards, and tentative revisions of standards.

Normally a proposed standard is first recommended for publication as tentative although in exceptional cases it may be recommended for immediate adoption as standard (see Section 15 (*c*)). At the end of one year, committees are expected to consider whether a tentative standard shall be adopted as standard with or without revision, or continued as tentative with or without revision. Similarly, revisions of standards are normally published as tentative for one year and then presented for incorporation in the standard.

A proposed standard recommended for publication as tentative should represent the best technical information available and should be in reasonably final form. Prior to reaching this state of development it may be desirable at times to make available a draft of the proposed standard by publication as information, either in the committee report or in the ASTM BULLETIN.

14. Procedure Governing Recommendations on Standards.—Recommendations of standing committees affecting standards shall be agreed upon only at meetings called for that purpose. An affirmative vote amounting to two-thirds of those voting shall be required on all recommendations affecting standards, subject to confirmation by letter ballot of the entire committee on which an affirmative vote amounting to two-thirds of those voting[b] shall also be required. The number of affirmative, negative, and "not-voting" ballots[c] shall be included in the report of the committee to the Society. If the number of negative votes on the letter ballot exceeds 10 per cent of the sum of the affirmative and negative votes, the report to the Society shall also contain a classification of the total vote as to producers, consumers, and general interests. (See Section 2 (*h*).)

Dissenting members shall have the right to present minority reports, individually or jointly, at the time at which the majority report is presented.

15. Procedure Governing the Promulgation of Standards:

(*a*) Acceptance of tentative standards, tentative revisions of standards, and revisions of tentative standards, and withdrawal of standards, tentative standards, and tentative revisions of standards, shall be either by action of the Society as provided in Paragraphs (*b*), (*c*), and (*d*) or of the Committee on Standards as provided in Paragraph (*e*). Adoption of standards and of revisions of standards, however, shall only be by action of the Society in annual meeting followed by letter ballot of the Society.

(*b*) An affirmative vote, amounting to two-thirds of those voting at the annual meeting, shall be required on all committee recommendations, except those involving immediate adoption of standards and immediate revision of standards. (For procedure on these exceptions see Paragraph (*c*).) These committee recommendations may be amended by an affirmative vote amounting to two-thirds of those voting, subject to approval of the revised recommendation by letter ballot of the committee; however, if the revised recommendation is rejected by the committee, the original committee recommendation shall be considered as approved by the Society and the proposed revision shall be referred to the committee for study and report at the next annual meeting.

(*c*) If immediate adoption as standard is recommended, either of a proposed new standard or of a revision of an existing standard without the usual preliminary publication as tentative, a nine-tenths rather than a two-thirds affirmative vote shall be required. In this case no amendment on the floor of the meeting shall be permitted, except with unanimous consent.

(*d*) Action of the Society at the annual meeting on the adoption or revision of standards is subject to approval by letter ballot of the Society, an affirmative vote amounting to two-thirds of those voting being required, except, that in the case of the immediate adoption of a standard or of the immediate revision of a standard without the usual publication as tentative, a nine-tenths rather than two-thirds affirmative vote shall be required.

(*e*) Committee recommendations on acceptance of tentative standards, tentative revisions of standards, and revisions of tentative standards, and on withdrawal of standards, tentative standards, and tentative revisions of standards, may also be presented between annual meetings to the Committee on Standards for action on behalf of the Society. The Committee on

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[b] "Those voting" consists of those casting either an affirmative or a negative vote.

[c] "Not-voting" ballots are those returned so marked.

Standards shall determine whether the requirements of the Society relating to committee procedure have been met and whether the committee has reached a satisfactory consensus. During consideration of the recommendation of a standing committee, representatives of the committee may be present and participate in the discussion. If the Committee on Standards takes favorable action upon the recommendation, the standing committee shall report the action in its next annual report.

16. Procedure for Recommended Practices.—The requirements of Sections 14 and 15 shall be applicable also in the establishment of recommended practices.

17. Matters of Engineering Design.—(This is the present Section 13 and is being continued without change.)

18. Standards Involving Patents.—(This is the present Section 16 and is being continued without change.)

Article IV.—To be revised as follows:

Section 17.—Change the first four paragraphs of the present Section 17 (changed to 19) read as follows by the additionof the italicized words and the omission of those in brackets:

19. Reports at Annual Meetings.—The reports of standing committees shall be presented at the annual meetings. [The report of every] Subcommittee*s* shall [be made] *report* to the parent committee and not to the Society direct. If [such] a *subcommittee* report is [embodied] *appended* wholly or in part [in] *to* the report of the parent committee [to the Society], the latter shall make definite reference[s] to such features [in its own report] and recommendations [if any, based thereon] *that the committee wishes to present to the Society.*

Standing committees shall include in their annual reports, in concise form, a statement of the essential facts regarding the origin of all proposed [new] standards and the reasons for proposing [amendments] *revisions* in existing standards and tentative standards. Appropriate data respecting [new] *proposed* methods of test or proposed [modifications] *revisions* of existing methods of test shall be included in such annual reports or filed with Committee E-1 on Methods of Testing, as may seem preferable. Reference to available publications shall be accepted as appropriate data.

Standing committees shall include in their annual reports, or in a formal statement to the Executive Committee of the Society in case there is no report for a given year, their reasons for continuing a tentative standard or tentative revision of an existing standard in the tentative status for more than [three] *two* years without revision or without recommendation for [advancement to] *adoption as* standard.

In the year in which the Book of Standards is issued, standing committees shall report, either to the Society or to the Executive Committee, whether all standards within their respective jurisdictions that have stood for six years or more without revision are still considered to be in accord with present practice and requiring no revision. *Should they so desire, standing committees may reapprove a standard of which no revision is found necessary, for the purpose of having such reapproval indicated on the standard, but without changing the year of adoption. Such reapproval shall require an affirmative letter ballot vote of the committee amounting to two-thirds of those voting, but shall not require a confirming letter ballot of the Society.*

(Remainder of this section continued without change.)

Section 18. Reports Between Annual Meetings.—Change to Section 20 and continue without revision except for references to section numbers.

Section 19. Advance Distribution of Reports.—Change to Section 21 and continue without revision.

Articles V to X, incl.—Change the section numbers in these articles to agree with the revised numbering.

The revisions of Article III accomplish several things. Most important, perhaps, is a restatement of the Society's standardization procedure in clearer and more understandable form, with respect both to standing committee and general Society procedure. The new Section 13 sets forth directly the various courses of action available to the committees in their development of standards. Section 14 is merely a restatement of the present section. Section 15 is also essentially a restatement of present procedure, with certain modifications necessitated by changes in the methods of publishing tentative standards, as noted hereinafter. The development of the Society's standardization activities has made it advisable to permit adoption of revisions of standards at any annual meeting as a regular rather than a special procedure and this is provided for in the revised Regulations. Moreover, immediate adoption of a new standard or of a revision of a standard without preliminary publication as tentative is given the status of a regular rather than an irregular or unusual procedure, although two new provisions are included: first, in Section 15 (*c*), that when immediate adoption is recommended, no amendment on the floor of the meeting shall be permitted except with unanimous consent; and second, in Section 16 (*d*), that the subsequent letter ballot of the Society, when immediate adoption has been recommended, shall require a nine-tenths affirmative vote for adoption instead of the usual two-thirds vote.

Of possibly equal importance is the decision to continue the "tentative status" in the standardization procedure. The significance and standing of the A.S.T.M. tentative standard have been the subject of some discussion in recent years, and a thorough study of this phase of our standardization procedure has been made. The chairmen and secretaries of standing committees, including the membership of Committee E-5, were invited to express their views. These views, briefly summarized, were that the tentative status should be continued, since most of the committees find it helpful in the development of standards; that in general the term "tentative" is preferable to other terms, such as "provisional"; and that the committees should in general seek adoption as standard more promptly. There was no general agreement as to whether there should be a definite time limit by which tentative standards must be adopted as standard or discontinued, —a proposal that has been advanced at various times. From this review of the subject it is recognized that some standards proposed by our committees for acceptance as tentative are practically in final shape and might almost warrant immediate adoption as standard, while others are in a very preliminary stage and represent perhaps the first attempt in arriving at a standard. There is a rather definite feeling that the latter should preferably be published not officially as tentative but simply as information.

After careful consideration of these views, as well as those of many other members and certain of the district committees, the revisions in those portions of Articles III and IV of the Regulations dealing with tentative standards were agreed upon. In Section 11 a new definition of the term "tentative standard" is given, which recognizes the dual purpose of publication and use prior to adoption as standard and opportunity for suggestion and criticism. In Section 13 it is set forth that a tentative standard should represent the best technical information available and should be in reasonably final form; otherwise, prior to reaching this state of development, drafts of proposed standards should be published for information either in the annual committee report or in the ASTM BULLETIN. Finally, in order to speed up, where desirable, the advancement from tentative to standard, present Section 17 of Article IV is being revised by changing from three to two years the period within which the committee must give reasons for continuing a tentative standard without revision or advancement to standard. One of the principal criticisms of the tentative status has grown from the practice of continuing tentative standards for comparatively long periods of time, and it is desired to place considerable emphasis on securing prompter action in advancement to standard. However, a proposal that tentative standards should either be advanced to standard within a year or dropped has seemed too drastic for adoption at this time.

Two other details are covered in these revisions. Definite provision is made for the procedure of withdrawing standards, which had not previously been covered. Then, in Article IV, Section 17, as revised, there is provided a procedure for reapproval by a standing committee of a standard of which no revisions are found necessary after a period of years. It is intended to indicate the fact of reapproval on the printed standard, but without change of the year of adoption. Committees may find such confirmation desirable, as showing that the standard is up-to-date despite the absence of any revisions for a number of years.

The Executive Committee has considered a suggestion that the members of standing committees shall serve thereon for a stated term, such as two years, thus involving periodic reappointment of all standing committees. This suggestion had been made in connection with the general question of termination of memberships on standing committees which had led to a modification of Section 2 (*f*) of the Regulations Governing Standing Committees, as reported a year ago. It was finally decided that any formal regulation covering periodic termination and reappointment of standing committees is inadvisable.

Some consideration has also been given by the Executive Committee and Committee E-5 on Standing Committees to the procedure on the floor of the annual meeting in receiving and acting upon committee recommendations affecting standards and tentative standards. The following procedure, which was tried out at the annual meeting last year and seemed to remedy some of the difficulties that developed under earlier procedures, has been adopted for use hereafter:

The committee chairman will present his report with all of its recommendations for standards and tentative standards and through suitable motion will ask for action collectively on these recommendations. The presiding officer will ask if there are any objections, giving ample time for objections to be registered from the floor. If there are no objections he will simply declare the motion adopted without calling for a formal vote. If there are objections the meeting must act separately on the one or more of the committee's recommendations to which objection has been made, and may then act collectively on the remainder.

The significant feature of this procedure is that it requires those who object to any recommendation of a standing committee to voice their objections so that such recommendation may be singled out for specific consideration. It places the burden of responsibility on the dissenter and more or less insures that the meeting will hear a reasonably adequate discussion of a disputed recommendation before it is asked to vote upon it. In this connection the Executive Committee suggests that members of standing committees who may dissent from a portion of the committee's report should make greater use of minority reports as provided in the Regulations.

Proposed Amendments of the By-laws:

The Executive Committee recommends that the following amendments of the By-laws be referred to a letter ballot vote of the Society for adoption:

Article II, Section 3.—Change the second sentence, covering the reporting of the results of the ballot on the election of officers, from its present form to read as follows by the addition of the italicized word and the omission of those in brackets:

> The letter ballot shall close at noon on the day preceding the opening of the Annual Meeting, and the result of the ballot shall be announced *during* [at the close of the first session of] the Annual Meeting.

Article IV, Section 2.—Change the second sentence to read as follows by the addition of the italicized words and the omission of those in brackets:

> He may appoint any other officer or member of the Society to preside at any designated session of *a meeting* [the Annual Meeting].

Article V, Section 1.—Change to read as follows by the addition of the italicized words:

> Section 1. The Society shall meet annually, *for the transaction of its business, including actions on standards,* at a time and place fixed by the Executive Committee. Twenty-five members shall constitute a quorum.

New Article VI.—Insert a new article as Article VI to read as follows, renumbering the present Articles VI, VII, VIII and IX accordingly:

> ARTICLE VI. ADMINISTRATIVE AND OTHER COMMITTEES
>
> Section 1. The Executive Committee shall create such committees and shall delegate to these committees such powers and functions as it finds desirable for the conduct of its business and for carrying out the purposes for which the Society has been organized, including the formation of committees for the development of standards.

Old Article VI (Renumbered Article VII).—Replace the present Section 1 by the following five sections:

> Section 1. The term "Standards" shall be applied collectively to standard specifications, standard methods, and standard definitions that have been approved by the sponsoring committee and adopted by the Society in accordance with the procedure established therefor.
>
> Section 2. The term "Tentative Standards" shall be applied to those specifications, methods, and definitions that have been approved by the sponsoring committee and accepted by the Society in accordance with the procedure established therefor, for publication and use preliminary to adoption as standard, thus providing opportunity for suggestion and criticism.
>
> Section 3. The term "Recommended Practices" shall be applied to processes and methods not ordinarily subject to contract between purchaser and manufacturer.
>
> Section 4. The procedure governing the promulgation of standards shall be as follows:
>
> (*a*) Acceptance of tentative standards, tentative revisions of standards, and revisions of tentative standards, and withdrawal of standards, tentative standards, and tentative revisions of standards, shall be either by action of the Society as provided in Paragraphs (*b*), (*c*), and (*d*) or of the Committee on Standards as provided in Paragraph (*e*). Adoption of standards and of revisions of standards, however, shall only be by action of the Society in annual meeting followed by letter ballot of the Society.
>
> (*b*) An affirmative vote, amounting to two-thirds of those voting at the annual meeting, shall be required on all committee recommendations, except those involving immediate adoption of standards and immediate revision of standards. (For procedure on these exceptions see Paragraph (*c*).) These committee recommendations may be amended by an affirmative vote amounting to two-thirds of those voting, subject to approval of the revised recommendation by letter ballot of the committee; however, if the revised recommendation is rejected by the committee, the original committee recommendation shall be considered as approved by the Society and the proposed revision shall be referred to the committee for study and report at the next annual meeting.
>
> (*c*) If immediate adoption as standard is recommended, either of a proposed new standard or of a revision of an existing standard without the usual preliminary publication as tentative, a nine-tenths rather than a two-thirds affirmative vote shall be required. In this case no amendment on the floor of the meeting shall be permitted, except with unanimous consent.
>
> (*d*) Action of the Society at the annual meeting on the adoption or revision of standards is subject to approval by letter ballot of the Society, an affirmative vote amounting to two-thirds of those voting being required, except, that in the case of the immediate adoption of a standard or of the immediate revision of a standard without the usual publication as tentative, a nine-tenths rather than two-thirds affirmative vote shall be required.
>
> (*e*) Committee recommendations on acceptance of tentative standards, tentative revisions

of standards, and revisions of tentative standards, and on withdrawal of standards, tentative standards, and tentative revisions of standards, may also be presented between annual meetings to the Committee on Standards for action on behalf of the Society. The Committee on Standards shall determine whether the requirements of the Society relating to committee procedure have been met and whether the committee has reached a satisfactory consensus. During consideration of the recommendation of a standing committee, representatives of the committee may be present and participate in the discussion. If the Committee on Standards takes favorable action upon the recommendation, the standing committee shall report the action in its next annual report.

Section 5. The requirements of Section 4 shall be applicable also in the establishment of recommended practices.

Renumber the present Section 2 as Section 6.

Articles VII, VIII, IX.—Renumber VIII, IX, X.

The amendments proposed in Articles II, IV, and V are substantially self-explanatory. The amendment to insert a new Article VI on "Administrative and Other Committees" is proposed for the purpose of providing definitely in the By-laws for the creation by the Executive Committee of various committees, such as standing, research, and administrative committees. This has long been a function of the Executive Committee under authority of Article IV, Section 1, vesting the general management of the Society in the Executive Committee, but it is believed desirable to set forth this specific authority separately because of its fundamental importance.

The amendment of Section 1 of present Article VI, which will become Article VII, Sections 1 to 5 inclusive, is directly related to the foregoing revisions in the Regulations Governing Standing Committees dealing with definitions of standards and tentative standards and the procedure governing the promulgation of standards. It will be seen upon comparison that the proposed new Sections 1 to 5 follow exactly, except for a few minor editorial changes necessitated by the context, Sections 10, 11, 12, 15 and 16 of the proposed revised Regulations Governing Standing Committees. Reference should be made to the discussion in connection therewith, which is equally applicable to this proposed amendment of the By-laws.

District Committees:

The district committees have done excellent work during the year in the interest of the Society, through the holding of local meetings under their sponsorship, through activities in securing new members, and in other ways. The Executive Committee wishes to express its appreciation to the officers and members of the district committees for the time and thought that they are devoting to this important work.

A new district committee, the ninth, was organized as the St. Louis District Committee on January 20, 1939, under the chairmanship of Past-President Hermann von Schrenk. An account of this meeting, together with the personnel of the committee, appeared in the March ASTM BULLETIN. St. Louis is the center of a large and important industrial area and the members in that region have strongly supported the organization of this new committee. Plans are under way for a fall meeting under the sponsorship of the committee.

In September, 1938, the Secretary-Treasurer visited the Northern and Southern California District Committees, conferring with them on their activities and their relationship with the work of the Society. Despite the physical handicap of distance from the center of Society activities, or possibly because of this very handicap, there is keen interest in many phases of Society work on the part of A.S.T.M. members in these localities. It is important to bring our Pacific Coast members as closely as possible into the activities of the Society, especially of its committees, and the district committees have been asked to recommend competent members for service on a number of the Society's standing committees. Considerable progress has been made in recent years in this direction. Increased local activities in the form of meetings sponsored by the district committees have been agreed to be desirable.

The third conference of officers of district committees was held during the Regional Meeting at Columbus in March, 1939. In addition to discussing several purely administrative questions, the conference brought out the importance of so developing the work of the Society that it will make a strong appeal to junior technologists in the industries of the country. It was believed that the district committees might help to advance this purpose by sponsoring meetings in the various districts of such a nature technically as to appeal particularly to such persons. The point was made that it is not sufficient to provide such programs at annual meetings of the Society since it is difficult for juniors in industry to attend the annual meetings.

Meetings:

The various meetings held during the past year have been fully reported in the ASTM BULLETIN so it is sufficient here simply to cite them as a matter of official record with an expression of appreciation to the many members and committees who helped to make these meetings successful.

The tenth Regional Meeting and spring group meetings of committees were held at Columbus, March 6 to 10, 1939, and featured two technical sessions: one dealing with the subject of Lime, under the auspices of Committee C-7 on Lime, and the other with Heat Insulating Materials, under the joint auspices of Committees C-8 on Refractories and C-16 on Thermal Insulating Materials. The total registration was 570, with upwards of 150 committee, subcommittee, and section meetings. Plans for the meeting were developed by a special committee of Columbus members serving under the chairmanship of C. E. MacQuigg.

The following local meetings were held under the auspices of the respective district committees: In Philadelphia on October 17, 1938; in Pittsburgh on November 14, 1938; in New York on November 17, 1938; in Detroit on April 19, 1939; in Cleveland on April 20, 1939; in Los Angeles on April 24, 1939; and in Chicago on May 18, 1939. Accounts of each of these meetings have appeared or will appear in the ASTM BULLETIN. President Delbridge attended the meetings at Philadelphia, Detroit, and Cleveland, and Vice-President Morgan those at Pittsburgh and Chicago, conveying appropriate greetings from the Society to the members and guests present. The Secretary-Treasurer conveyed similar greetings on behalf of the President at the New York meeting.

Plans for a regional meeting this year in San Francisco during the Golden Gate Exposition were deemed not to be feasible after consideration with the Northern California District Committee.

As to meetings during the coming year, the Executive Committee announces that the next Regional Meeting and spring group committee meetings will be held in Detroit, March 4 to 8, 1940. The next annual meeting will be held at Atlantic City, June 24 to 28, 1940.

Publications:

The Society's publications in the very nature of things represent its most important single activity inasmuch as they are the tangible expression of the results of the Society's work through its committees and through the papers and discussions at its various meetings. In addition to the normal publication activities, under Committee E-6 on Papers and Publications important changes in certain publications, as explained below, have served to make this an unusually busy publication year.

The following regular publications were issued and distributed to the members:

1938 Proceedings: Part I (Committee Reports) 1404 pages; Part II (Technical Papers) 680 pages; total 2084 pages, 4700 copies each part; in addition to preprints of reports and papers totaling approximately 1220 pages.

1938 Supplement to Book of A.S.T.M. Standards, 251 pages, 8900 copies.

Supplement to A.S.T.M. Methods of Chemical Analyses of Metals, 35 pages, 1000 copies.

1939 Index to Standards and Tentative Standards, 140 pages, 13,500 copies.

Year Book, 286 pages, 3000 copies.

ASTM BULLETIN, six issues, August 1938 to May 1939, 356 pages; average edition, 6300 copies.

The Book of A.S.T.M. Tentative Standards (1796 pages, 2000 copies) and the Symposium on Plastics at the Rochester Regional Meeting, March, 1938 (57 pages, 2000 copies) were published and furnished to members on order.

A comparative statement of the volume of the above-mentioned publications for the past four years follows:

Publication	1935, pages	1936, pages	1937, pages	1938, pages
Proceedings	2279	2111	2092	2084
Book of A.S.T.M. Standards	......	2419	......	......
Supplement to Book of A.S.T.M. Standards	216	......	282	251
A.S.T.M. Methods of Chemical Analyses of Metals	......	260	260	35
Index to A.S.T.M. Standards and Tentative Standards	142	160	120	128
Year Book	256	246	272	286
Book of A.S.T.M. Tentative Standards	1628	1422	1664	1796
Regional Meeting Symposiums	156	132	232	57
	4677	6750	4922	4637

During the past year the Society also published the following compilations of standards:

A.S.T.M. Standards on Cement (Committee C-1), 111 pages, 1000 copies, published annually.

A.S.T.M. Standards on Petroleum Products and Lubricants (Committee D-2), 320 pages, 4900 copies, published annually.

A.S.T.M. Standards on Coal and Coke (Committee D-5), 160 pages, 1700 copies, published biennially.

A.S.T.M. Standards on Electrical Insulating Materials (Committee D-9), 371 pages, 700 copies, published annually.

A.S.T.M. Standards on Textile Materials (Committee D-13), 334 pages, 1600 copies, published annually.

A.S.T.M. Specifications for Pipe and Pipe Materials for High-Temperature and High-Pressure Services (Committee A-1), 134 pages, 750 copies; a new compilation.

Other special publications printed since the last annual meeting include:

Symposium on Consistency—Critical Discussion of Present-day Practices in Consistency Measurement, 79 pages, 750 copies.

Symposium on Protecting Metals Against Corrosion (Detroit District Meeting, April, 1938), 30 pages, 1500 copies.

Compilation of Available High-Temperature Creep Characteristics of Metals and Alloys, published jointly with the American Society of Mechanical Engineers, 864 pages, 1000 copies.

Data Forms on Effect of Temperature, 2000 copies.

Index to Literature on Spectrochemical Analysis, sponsored by Committee E-2, 61 pages, 1000 copies.

Special reprints from the Proceedings include:

Report of Committee A-5 on Corrosion of Iron and Steel, 30 pages, 1250 copies.

Marburg Lecture, "The Torsion Test," by Albert Sauveur, 22 pages, 1000 copies.

Symposium on Impact Testing, 163 pages, 2000 copies.

The expansion of the ASTM BULLETIN begun in 1936, notably by the inclusion of important technical papers and reports, has been continued during the past year. The extent of this expansion may be seen from the fact that the six issues of the ASTM BULLETIN in 1937 contained 206 pages of text matter of which 70 pages (or about 35 per cent) represented technical material in the form of papers, reports and special articles of a character not theretofore appearing in the BULLETIN; whereas the six issues of the BULLETIN in 1938 contained a total of 267 pages of text matter which include 121 pages of technical material (or about 45 per cent). Many expressions of opinion from the members of the Society have made it clear that the enlarged BULLETIN is meeting with very general favor.

Format of Society Publications.—A study by Committee E-6 on Papers and Publications of the adaptability to the standards of the Society of the double-column format that has been used for several years for technical papers and last year for committee reports, has led to the decision to reset the standards and tentative standards in this new style. In consultation with the officers of standing committees, a format has been adopted that has received very general approval and will result in standards of improved appearance and readability with an estimated saving in space of approximately 20 per cent. This new style was used last fall for the 1938 Supplement to the Book of Standards and for the compilation of A.S.T.M. Standards on Petroleum Products and Lubricants. Beginning early this year the resetting of standards and tentative standards has been vigorously pushed, with the hope that the new publications to be issued later in the year may be substantially all in the new format.

It is estimated that the total cost of resetting existing standards and tentative standards will be approximately $15,000. The contract for this work, including the publication thereafter of Proceedings and Book of Standards and Tentative Standards, has been given to Waverly Press of Baltimore, with the understanding that the costs of resetting will be paid from the savings effected and spread over a period of five or more years.

New Method of Publishing Standards and Tentative Standards.—As announced to the members of the Society in the formal printed communication dated November 8, 1938, a new method of publishing the standards and tentative standards of the Society has been adopted. While present methods of publication have served the Society's needs well for many years, the rapid growth of our standardization work and the increasing diversification of Society activities have introduced complexities and difficulties, and new methods better suited to present-day requirements are needed. The magnitude of this growth is evident from the single statistic that the number of standards and tentative standards has increased 70 per cent in the past decade. As a result, Part I of the Proceedings containing new and revised tentative standards, and especially the annual Book of Tentative Standards, have become unwieldy in size and therefore difficult to use. It is frequently inconvenient to locate certain specifications or methods when reference back and forth between the Book of Standards and Proceedings is necessary. Furthermore the Book of Tentative Standards has covered the entire materials field, whereas many members are interested in only a limited portion of the field. These and other considerations made it clear that the members of the Society would be better served if the standards and tentative standards appeared in the same instead of different publications, and careful study of a realignment of publications on this principle has demonstrated its advantages.

Accordingly, the present triennial Book of Standards in two parts with its supplements, the section of Proceedings containing new and revised tentative standards and the annual Book of Tentative Standards, will be combined into a single publication—a Book of A.S.T.M. Standards and Tentative

Standards. This will be published triennially in three parts beginning in 1939, as follows: Part I, Metals; Part II, Non-Metallic Materials—Constructional; Part III, Non-Metallic Materials—General. The contents of these three parts were defined in the above-mentioned communication; the 1939 editions of each part will be about 1300 pages. Supplements to each part published in the two succeeding years with cloth binding will contain all new standards, new and revised tentative standards, and tentative revisions of standards. New and revised tentative standards will no longer be included in the annual Proceedings, which will hereafter be published conveniently in a single volume containing committee reports and technical papers. The annual Book of Tentative Standards will no longer be published. The Methods of Chemical Analyses of Metals will still be issued as a separate publication free to members upon request. The annual Index to Standards and Tentative Standards, compilations of standards and tentative standards in specific industrial fields and the usual separate reprints of standards will continue to be published. In line with the present policy of distributing the Book of Standards, members will be entitled to any *one* part of the new Book of Standards and Tentative Standards and its supplements; members desiring any *two* or all *three* parts of the Book, with their respective supplements, will pay annually $1.50 and $2.50 respectively.

It is very gratifying to report that this new plan of publication seems to have met with very general approval. Many favorable comments have been made and very few adversely. It is interesting to record that on the basis of returns from about 80 per cent of the Society membership, approximately 45 per cent of the members have requested one of the three parts (23 per cent Part I, 11 per cent Part II and 11 per cent Part III), 10 per cent have requested two parts, and 45 per cent have requested all three parts.

Sales prices for the new publications to non-members and special prices to members for extra copies have been announced.

The next decade will almost certainly see the greatest expansion of our standardization and publication activities that has yet taken place, and under this new plan the way is cleared for development and growth along the soundest and most effective lines.

Finances:

Report for the Fiscal Year 1938.—The annual statement of the finances of the Society follows in the report of the auditors for the fiscal year, January 1 to December 31, 1938. The report gives the balance sheet of assets and liabilities, including special and designated funds (that is, the Research Fund, Medal and Lecture Fund, and Committee Funds); statement of receipts and disbursements, in which the items are classified into "operating" (budgeted) and "non-operating"; details of special funds; and investment of Society funds, both book and market values being given.

Total receipts from dues and entrance fees in 1938 were $80,539.41, a slight increase over corresponding receipts for the preceding year. Receipts from sales of publications totaled $48,454.80, being the second highest figure in the Society's history. The percentage ratio to total receipts is 34 per cent, which is about average for recent years. The fact that approximately one-third of the Society's income is derived from sale of its publications is significant in showing the

Society's dependence on this source of income as a means of carrying on its work. Miscellaneous receipts amounted to $12,037.55, consisting principally of receipts from advertising in the ASTM BULLETIN and in the Index to Standards and Tentative Standards, interest on deposits and investments, and registration fees. BULLETIN advertising for last year was about one-sixth under the previous year; advertising in the Index was slightly increased.

Total operating receipts were $141,031.76. Total operating disbursements with all current bills paid, as detailed in the auditors' report, and including $6000 reserve for publication of the 1939 Book of Standards and $1400 paid into the principal of the Research Fund, were $142,818.45. The resulting deficit of $1786.69 was met from reserves acquired from the previous year's operation. However, since an operating deficit of $9000 for the year had been anticipated when the budget was drawn, the Society's current operations for the year came out about $7000 better than had been anticipated.

The auditors' report includes a comparison of the financial condition of the Society at the close of each of the past five years. The surplus in the general funds account, exclusive of special and designated funds, is $57,332.84, which compares with $58,619.60 a year ago.

Investments of Society funds as of December 31, 1938, are given in the auditors' report, both book and market values being shown. During 1938 approximately $10,000 of surplus was invested in dividend-paying common stocks of five corporations; four of the five lots were sold before the close of the year, yielding a profit of about $2400; the fifth lot, namely, 50 shares of General Electric common, remains in the investment portfolio. One transfer of investment was made, from $3000 Oklahoma Natural Gas first mortgage 4½ per cent bonds to $3000 Michigan Consolidated Gas first mortgage 4 per cent bonds. Uninvested principal in the A.S.T.M. Research Fund at the close of 1937 was invested in $1000 Baldwin Locomotive Works first mortgage 5 per cent bond and $1000 Allis-Chalmers Manufacturing Co. convertible debenture 4 per cent bond.

Although none of the bonds in the investment portfolio are in default, all of the bonds of the Baltimore & Ohio Railroad Co. totalling $17,000 in three funds are subject to the plan of modification of interest charges and maturities proposed by the company. Under this plan the interest on the bonds owned by the Society will be reduced to 20 per cent of the coupons, the remaining 80 per cent being cumulative with payment dependent on future earnings. The Society has agreed to the plan of modification and deposited the bonds with a trustee.

No account has been taken in the accompanying financial statement of the assets of the Society in the form of publications in stock, with the exception of the cost value, $1069.88, of the copies still in stock of the Joint A.S.M.E.-A.S.T.M. Symposium on Effect of Temperature on the Properties of Metals purchased by the Society from a joint account; this amount is included in the statement of assets. There appears in the statement of liabilities the sum of $314.31, which represents net profit to December 31, 1938, on the A.S.T.M.-A.S.M.E. Creep Data Volume likewise published jointly and handled through a separate account as a "non-operating" item. An inventory of technical publications on June 1, 1939, may be summarized as follows:

	Number of Copies
Year Book	171
Proceedings	4 891
Index to Proceedings, 5 parts, total	1 557
1936 Book of A.S.T.M. Standards:	
Part I, Metals	155
Part II, Non-Metals	423
1937 Supplement to Book of Standards	253
1938 Supplement to Book of Standards	627
1938 Book of A.S.T.M. Tentative Standards	433
Index to Standards and Tentative Standards	2 625
Selected Standards for Students in Engineering	517
Reprints of Standards and Tentative Standards (approximate)	55 000
Symposium on Effect of Temperature on the Properties of Metals	263
Creep Data Volume	403
Special Reprints (approximate)	28 500

1939 Finances.—Society operations for 1939 are based upon budgeted operating receipts of $154,000, of which $149,400 is estimated current receipts and $4600 is applied to 1939 operations from surplus. Receipts from dues and entrance fees are estimated at $82,250, receipts from sales of publications at $51,700 and miscellaneous receipts, including advertising, exhibit, and interest, at $15,450. Disbursements have been estimated at $153,250, leaving $750 for contingencies. The budget provides fully for all of the Society's normal operating expenses, including the cost of the new Book of Standards and Tentative Standards towards which the reserve of $12,000 accumulated during the past two years will be applied.

The Executive Committee reviews the budget of receipts and disbursements quarterly and makes any adjustments of appropriations for operating expenses that may be needed in the light of actual receipts.

The policy is being continued of increasing the proportion of Society funds invested in dividend-paying common stocks. Thus, $4000 Montana Power Co. first mortgage $3\frac{3}{4}$ per cent bonds were sold and the proceeds invested in 40 shares of common stock of the American Can Co. Surplus funds amounting to approximately $14,000 have been invested in the common stocks of the following seven corporations: American Cyanamid Co., American Radiator and Standard Sanitary Corp., American Tobacco Co., Hazel Atlas Glass Co., Sears Roebuck and Co., Standard Oil Co. of New Jersey, and United Gas Improvement Co. These investments, of course, do not appear in the present auditors' report. They bring the total book value of Society investments to about $89,300, of which approximately 64 per cent is in bonds, 6 per cent in preferred stocks and 30 per cent in common stocks.

Further Financial Problems.—Important financial questions face the Executive Committee in the immediate future. Reference has been made earlier in this report to the growing demand from industry for specifications and methods of test, which is reflected in the creation of new committees, the continued expansion of the work of existing committees and the increase in number of standards of about 70 per cent in the past ten years. This increase has taken place during a period of business depression which has held down the growth of membership, so that actually the income from membership dues today is somewhat less than it was ten years ago. However, the increased sales of publications, which is one form of industry support of our work, has more than offset this loss, and has alone made possible the expansion that has taken place. Expressed in another way, the activities and "output" of the Society have been developing more rapidly than its membership, and since membership is the bone and sinew of a technical society such as ours, it seems that for sound and healthy development in the future the Society needs substantially to extend its membership and the income therefrom. Hence, the emphasis upon sustaining membership as one means of increasing support of Society work. A wider membership base is essential when we consider the new fields into which we are being drawn. Important develop-

REPORT OF THE AUDITORS FOR THE FISCAL YEAR, JANUARY 1, 1938 TO DECEMBER 1, 1938

Philadelphia, January 10, 1939.

Mr. C. L. Warwick, *Secretary-Treasurer*,
American Society for Testing Materials
Philadelphia, Pa.

Dear Sir:

We have examined the books and accounts of your Society for the year ended December 31, 1938, but we did not make a detailed audit of all transactions.

We have prepared the accompanying Balance Sheet as of December 31, 1938, Statement of Cash Receipts and Disbursements for the twelve months ended that date, and other supporting schedules, all of which are in agreement with the records of the Society. These statements, in our opinion, fairly present the financial position of the Society as of December 31, 1938, and the results of its operations for the year.

Investments owned as detailed were examined by us, with the exception of $17,000 Baltimore & Ohio R. R. Co. Gen. & Ref. Bonds which were deposited with the Girard Trust Co. under plan of modification of interest charges and maturities and for which a receipt of said depository was submitted.

All income from investments was properly accounted for. In this connection the income from 98 shares of General Motors Co. stock is not included in the income of the Society in any of the schedules herein, as this is payable to an annuitant as and when received under agreement dated February 20, 1937.

Respectfully submitted,
(signed) John Heins & Company.

BALANCE SHEET AS OF DECEMBER 31, 1938
(Including Special and Designated Funds)
ASSETS

General Funds:			
Current: Cash	$39 075.51		
Less checks drawn as of December 31, 1938—Cost of Proceedings in hands of Secretary-Treasurer that date	14 650.00		
		$24 425.51	
Investments (Market Value, $30 238.13)—Cost		39 568.24	
Accounts Receivable		8 539.12	
Total Current Assets—General Fund			$72 532.87
Furniture and Fixtures			6 912.96
A.S.T.M.-A.S.M.E. Symposium on Effect of Temperature: Special Account for Financing Book			1 069.88
Total General Funds			$80 515.71
Special and Designated Funds:			
Cash: A.S.T.M. Research Fund		$1 668.53	
Dudley Medal and Marburg Lecture Fund		693.90	
Committee Funds		6 896.28	
			9 258.71
Investments:			
A.S.T.M. Research Fund (Market Value, $16 181.89)—Cost or book value		$21 660.07	
Dudley Medal and Marburg Lecture Fund (Market Value, $1 303.75)—Cost		6 625.00	
Committee Funds (Market Value $6 397.81)—Cost		6 000.00	
			34 285.07
Total Special and Designated Funds			$43 543.78
Total Assets			$124 059.49

Total Assets (brought forward)			124 059.49

LIABILITIES

General Funds:			
Current: Accounts Payable:			
Committee C - 1	$197.95		
Advance Collections	2 085.93		
Total Current Liabilities—General Fund		$2 283.88	
Life Membership Fund	$3 005.20		
Headquarters Fund	2 564.48		
Publication Fund	3 015.00		
A.S.T.M.-A.S.M.E. Creep Data Volume	314.31		
Book of Standards Reserve	12 000.00		
Surplus	57 332.84		
		78 231.83	
Total General Funds			$80 515.71
Special and Designated Funds:			
A.S.T.M. Research Fund		$23 328.60	
Dudley Medal and Marburg Lecture Fund		7 318.90	
Committee Funds		12 896.28	
Total Special and Designated Funds			43 543.78
Total Liabilities and Funds			$124 059.49

COMPARISON OF GENERAL FUNDS FOR FISCAL YEARS 1934–1938, INCLUSIVE

At Close of Fiscal Year	Assets				Liabilities			
	Cash	Investments	Accounts Receivable and Miscellaneous	Furniture and Fixtures	Accounts Payable and Miscellaneous	Reserve for Book of Standards	Miscellaneous Funds	Surplus
1934	$3 792.12	38 924.05	9 767.35	8 010.84	2 204.99	5 023.44	7 061.76	46 204.17
1935	10 514.73	36 180.42	9 220.39	7 489.70	2 695.60	10 023.44	7 061.76	43 624.44
1936	6 943.82	29 767.23	16 088.91	6 915.95	2 624.62	....	7 061.76	50 029.53
1937	20 686.08	37 599.49	10 506.78	7 029.87	2 140.86	6 000.00	9 061.76	58 619.60
1938	24 425.51	39 568.24	9 609.00	6 912.96	2 283.88	12 000.00	8 898.99	57 332.84

RECEIPTS AND DISBURSEMENTS

FOR THE PERIOD JANUARY 1, 1938, TO DECEMBER 31, 1938

Cash balance, January 1, 1938			$20 686.08
RECEIPTS			
Operating Receipts (Budgeted):			
Dues and Entrance Fees:			
Current Dues	$75 667.48		
Past Dues	618.00		
Advance Dues	1 281.43		
Income, Life Membership Fund	150.00		
Entrance Fees	2 822.50		
Total Dues		$80 539.41	
Sale of Publications:			
Separate Standards	$6 459.37		
Book of Standards	8 565.21		
Book of Standards (Members, both parts)	315.00		
Book of Tentative Standards	6 985.86		
Methods of Chemical Analysis of Metals	886.68		
Proceedings	3 546.07		
Selected Standards for Students	911.15		
Bulletin Subscriptions (Non-Members)	257.20		
Special Reprints and Miscellaneous	20 528.26		
Total Sale of Publications		$48 454.80	
Miscellaneous:			
Binding (Members)	$227.00		
Advertising, Bulletin	5 488.70		
Advertising, Index	1 642.40		
Interest on Deposits and Investments	2 516.35		
Registration and Other Fees, Annual Meeting	1 237.00		
A.S.T.M. Exhibit, Annual Meeting	138.90		
Committee A - 1 for Technical Assistant	725.00		
Miscellaneous	62.20		
Total Miscellaneous Items		$12 037.55	
Total Operating Receipts (Budgeted)		$141 031.76	
Non-Operating Receipts (Not Budgeted):			
Investments, Matured or Sold	$17 419.57		
Excess Remittances	141.50		
Seaview Golf Club	39.98		
Creep Data Volume	4 725.23		
Symposium on Effect of Temperature	189.55		
Committee C - 1 for Technical Assistant	1 700.00		
Committee E - 4 (Polishing Cloth)	541.04		
Total Non-Operating Receipts		24 655.87	
Total Receipts			165 787.63
Carried forward			$186 473.71

Brought forward			$186 473.71

DISBURSEMENTS

Operating Disbursements (Budgeted):			
Publications:			
Year Book	$1 901.86		
Book of Standards Supplement	2 509.56		
Book of Tentative Standards	4 851.38		
Methods of Chemical Analysis of Metals	38.65		
Proceedings	20 007.48[a]		
Preprints	2 798.52		
Regional Meeting Papers	329.03		
A.S.T.M. Bulletin	6 524.55		
Circulars to Members	1 659.25		
Separate Standards	2 855.94		
Index to Standards and Tentative Standards	1 714.06		
Reprints (Reports, Papers, Symposiums, etc.)	5 863.95		
Miscellaneous Printing (Authors' Reprints, etc.)	479.96		
Resetting Standards (Double Column)	2 128.77		
Total Disbursements, Publications		$53 662.96	
Salaries		53 472.84	
General Office Expenses		11 503.15	
Expenses, Standing and District Committees		4 008.19	
Expenses, Meetings and A.S.T.M. Exhibit		3 083.59	
Traveling Expenses, Administrative and Special Committees		2 109.22	
American Standards Assn. and Sectional Committees		1 000.00	
Rent, Headquarters		5 100.00	
Furniture and Fixtures		870.66	
Principal, A.S.T.M. Research Fund (one-half current year's entrance fees)		1 400.00	
Employees Retirement Fund		434.83	
Miscellaneous		173.01	
Total Operating Disbursements (Budgeted)		$136 818.45	
Non-Operating Disbursements (Not Budgeted):			
Investments	$16 816.58		
Accrued Interest	13.33		
Refund of Excess Remittances	141.50		
Seaview Golf Club	38.95		
Headquarters Fund	477.08		
Purchase of Retirement Income	1 000.00		
Symposium on Effect of Temperature	6.00		
Creep Data Volume	4 681.93		
Technical Assistant, Committee C-1	1 562.02		
Committee E-4 (Polishing Cloth)	492.36		
Total Non-Operating Disbursements		25 229.75	
Total Disbursements			$162 048.20
Cash Balance, December 31, 1938			$24 425.51

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[a] This amount includes $14,650.00 in the form of checks drawn against cost of *Proceedings*, but not actually paid on December 31, 1938, pending final completion of the publication work.

In addition to the general funds of the Society, the Secretary-Treasurer has on hand the following funds:

A.S.T.M. RESEARCH FUND

Principal Account:	*Total*	*Invested*	*Uninvested Cash*
Balance January 1, 1938, as Reported	$21 313.26	$19 633.26	$1 680.00
Receipts—Contribution—Committee D - 14	+14.92		+14.92
Contribution—H. F. Moore	+150.00		+150.00
Contribution—A.S.T.M. Entrance Fees	+1 400.00		+1 400.00
	$22 878.18	$19 633.26	$3 244.92
Disbursements—Purchase of Securities		+2 026.81	−2 026.81
Balance, December 31, 1938	$22 878.18	$21 660.07	$1 218.11

Income Account:		
Cash Balance, January 1, 1938	$1 251.68	
Receipts—Interest on Deposits and Investments	701.08	
		$1 952.76
Disbursements:		
Capping Tests of Hollow Tile (Committee C - 15)	$75.00	
Power Factor Cell (Committee D - 9)	277.16	
Shipment of Soil Samples (Committee D - 18)	50.18	
Joint Project University of Illinois on Speed of Testing Metals (Committee E - 1)	600.00	
Research Committee on Fatigue of Metals	500.00	
		1 502.34
Cash Balance, December 31, 1938		$450.42

DUDLEY MEDAL AND MARBURG LECTURE FUND

Balance, January 1, 1938:			
Principal—Investments (At Cost)	$6 625.00		
Income—Cash	627.92		
		$7 252.92	
Receipts			
Interest on Investments	330.00		
		$7 582.92	
Disbursements			
Honorarium, 1938 Lecturer	$200.00		
Cost of 1938 Medal	35.70		
Engrossing 1938 Lecture Certificate	3.32		
Miscellaneous	25.00		
		264.02	
Balance, December 31, 1938:			
Principal—Investments (At Cost)		$6 625.00	
Income—Cash		693.90	
			$7 318.90

COMMITTEE FUNDS

Committee A – 1 on Steel	$794.54	
Committee A – 5 on Corrosion of Iron and Steel	3 336.81	
Committee A – 5, Subcommittee X on Embrittlement Investigation	135.59	
Committee B – 3 on Corrosion of Non-Ferrous Metals and Alloys	3 190.10	
Committee B – 6 on Die-Cast Metals and Alloys	179.42	
Committee C – 1 on Cement	977.94	
Committee C – 1, Cement Reference Laboratory	731.17	
Committee C – 1 on Cement, Studies of Additions to Cement	65.07	
Committee C – 9 on Concrete and Concrete Aggregates	$177.72	
Committee C – 9 Sanford E. Thompson Medal Fund	550.00	
Committee C – 15 on Manufactured Masonry Units	303.56	
Committee C – 18 on Natural Building Stones and Slate	167.76	
Committee D – 1 on Paint, Varnish, Lacquer, and Related Products	37.19	
Committee D – 2 on Petroleum Products and Lubricants	67.53	
Committee D – 13 on Textile Materials	316.26	
A.S.A. Sectional Committee on Specifications for Cast-Iron Pipe and Special Castings	208.97	
A.S.A. Sectional Committee on Classification of Coals	1 156.65	
Research Committee on Fatigue of Metals	500.00	
Total Committee Funds		$12 896.28
Accounted for as follows:		
Investments (At Cost)	$6 000.00	
Cash Balance, December 31, 1938	6 896.28	
		$12 896.28

INVESTMENTS, DECEMBER 31, 1938

GENERAL FUNDS

Par Value:		*Book Value*	*Market Value*[1]
$9 000	Baltimore & Ohio R. R. Refunding and General Mortgage Bonds, Series F, 5's, due 1996	$9 106.55	$1 698.75
4 000	New York, Chicago & St. Louis R. R. Refunding Mortgage Bonds, Series C, 4½'s, due 1978	2 805.61	2 140.00
3 000	Wheeling Steel Corp., First Mortgage Sinking Fund Bonds, Series A, 4½'s, due 1966	3 045.00	2 812.50
3 000	Republic Steel Corp., General Mortgage Bonds, Series B, 4½'s, due 1961	3 000.00	2 790.00
2 000	North Station Industrial Bldg., Inc., First Mortgage Sinking Fund Bonds, 5's, due 1962	1 850.00	860.00
500	Saguenay Power Co., Ltd., First Mortgage Sinking Fund Bonds, Series A, 4¼'s, due 1966	500.00	529.38
3 000	Armour and Co., First Mortgage, 20-yr. Sinking Fund Bonds, Series C, 4's, due 1957	2 955.00	2 947.50
3 000	Pennsylvania State Water Corp., First Collateral Trust Bonds, 4¼'s, due 1966	2 850.00	2 932.50
4 000	Montana Power Co., First and Refunding Mortgage Bonds, 3¾'s, due 1966	3 780.00	3 870.00
3 000	Michigan Consolidated Gas Co., First Mortgage 4's, due 1963	2 925.00	2 902.50
	50 shares Great Northern Ry. $6.00 Preferred Stock, par value $100	1 774.83	1 493.75
	30 shares Northern States Power Co., $5 Preferred Stock, no par value	2 970.00	3 086.25
	50 shares General Electric Co., Common Stock, no par value	2 006.25	2 175.00
		$39 568.24	$30 238.13

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[1] Market Values, except on First Mortgage Real Estate 1315–1317 Spruce Street, 6's, 1945, on which there was no available quotation, have been taken from the Bank and Quotation Record as of December 31, 1938.

A.S.T.M. RESEARCH FUND

$1 500	Baltimore & Ohio R. R. Refunding and General Mortgage Bonds, Series F, 5's, due 1996	$1 511.25	$283.13
2 000	New York, Chicago & St. Louis R. R. Refunding Mortgage Bonds, Series C, 4½'s, due 1978	1 400.26	1 070.00
2 000	First Mortgage Real Estate Bonds, 1315–1317 Spruce St., Philadelphia, 6's, due 1945	2 000.00	1 200.00
3 000	North Station Industrial Bldg., Inc., First Mortgage Sinking Fund Bonds, 5's, due 1962	2 812.50	1 290.00
$1 500	Saguenay Power Co., Ltd., First Mortgage Sinking Fund Bonds, Series A, 4¼'s, due 1966	1 500.00	1 588.13
1 000	Baldwin Locomotive Works, First Mortgage, Sinking Fund Bonds, 5's, due 1940	991.53	1 002.50
1 000	Allis Chalmers Mfg. Co., Convertible Debentures, 4's, due 1952	1 035.28	1 097.50
	29 shares Consumers Power Co., $4.50 Preferred Stock, no par value	2 914.50	2 747.75
	10 shares Northern States Power Co., $5 Preferred Stock, no par value	990.00	1 002.88
	98 shares General Motors Corp., Common Stock, par $10[a]	6 504.75	4 900.00
		$21 660.07	$16 181.89

DUDLEY MEDAL AND MARBURG LECTURE FUND

$500	Baltimore & Ohio R. R. Refunding and General Mortgage Bonds, Series C, 6's, due 1995	$550.00	$103.75
6 000	Baltimore & Ohio R. R. Refunding and General Mortgage Bonds, Series A, 5's, due 1995	6 075.00	1 200.00
		$6 625.00	$1 303.75

COMMITTEE FUNDS

$5 000	U. S. Treasury Bonds, 2¾'s, due 1947	$5 000.00	$5 351.56
1 000	U. S. Treasury Bonds, 2⅞'s, due 1960	1 000.00	1 046.25
		$6 000.00	$6 397.81
		$73 853.31	$54 121.58

ments in standards for "consumer goods," so-called, are to be expected, which will bring important problems to us for consideration; indeed, they are with us already in such fields as textiles and detergents. Adequate financial support of such expansion as this is a problem of major importance.

Another phase of the problem is related to the fact that the members today are receiving for the same dues at least 50 per cent more by way of standards, tentative standards, committee reports and technical papers than they did ten years ago. Hence in the major realignment of publications previously mentioned, the Executive Committee has sought to place the new Book of Standards and Tentative Standards on a substantial financial basis, in the fixing of general sales prices and the charges to members for the several parts of the new book. Whether this has been accomplished can only be told from the experiences of the next three years, since present charges and prices have necessarily been based upon estimated membership growth and sales for that period. The aim has been to give to the members the maximum in value of publications and other services within the present dues and at the same time provide an adequate financial foundation for the growth of the Society's work.

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[a] The income from these shares is by agreement paid to an annuitant.

Retirement Plan for Employees:

The Retirement Plan for A.S.T.M. Employees, announced and briefly described in the 1938 report, has been in effect since May 3, 1938, and is now participated in by eighteen of the Society's twenty employees. The Society's contributions for the first year to the eighteen Deferred Income Policies in the Penn Mutual Life Insurance Co. of Philadelphia that have been set up for retirement income totaled $664.91 (approximately $1\frac{1}{3}$ per cent of the annual salary roll) and were matched by the respective employees.

The Executive Committee has found it possible to increase the Society's contribution approximately 50 per cent, effective on the first anniversary of the Plan, bringing the total annual Society contribution to approximately $1080, which is 2 per cent of the present salary roll. The increase has been applied to the purchase of income policies for certain employees of longer service, who match the Society's contribution. Any additional premium required to obtain special features, such as insurance, is paid for entirely by the employee in all policies after the initial one.

The sum of $1000 was applied in 1938 from surplus toward retirement income for the Secretary-Treasurer.

This first extension of the Retirement Plan has resulted in establishing retirement incomes more nearly commensurate with the retirement needs to be met, at the same time requiring from employees of longer service monthly contributions more nearly commensurate in proportion to salary with the contributions of those of shorter service. Better all-around balance has thus been effected. Future enhancements of the Plan, if and when made, will take into account such factors as earnings, length of service, ratio of each employee's contribution to salary and ratio of retirement income to salary.

Headquarters:

The lease on the present headquarters, comprising approximately 4000 sq. ft., has been extended to December 31, 1941, at a satisfactory rental. The new space acquired January, 1938, has relieved earlier crowded conditions. The general offices, board room and reception room, located on the fifth floor of the building, comprise about 3150 sq. ft. and will be adequate for some time. The shipping and publication storage space on the fourth floor (now 850 sq. ft.) may soon require expansion.

Cooperative Activities:

The Society's activities have always of necessity involved cooperative relations with many other organizations, which relations proceed along well-established lines. News items in the ASTM BULLETIN have told of various activities in this direction and these need not be repeated. Several happenings, however, merit specific mention here.

The Society's contacts with the American Standards Association constitute one of its most important cooperative activities. During the past year the principal work has been more or less routine in nature, involving the submission of new and revised standards to the A.S.A. for approval as American standard. The report of Committee E-10 on Standards presents this work in detail.

The Society has, at its request, been accorded membership on A.S.A. Sectional Committee C29 on Insulators for Electric Power Lines, primarily to coordinate the work of Committee D-9 on Electrical Insulating Materials with that of Committee C29. The present A.S.T.M. Tentative Method of Testing Pin-Type, Lime Glass Insulators

(D 468 - 38 T), developed by Committee D-9, will be cleared through the sectional committee for ultimate approval by the A.S.A. as American standard, and Committee D-9 will be recognized as the group to which the sectional committee can continue to look for the detail work in connection with glass insulators. The Society's representatives on the sectional committee, selected from D-9's section on glass insulators, are: U. E. Bowes, Merrill DeMerit, V. F. Hammel, and H. A. Wadman.

Other appointments to A.S.A. sectional committees during the year are: James Aston to B31 on Code for Pressure Piping and B36 on Wrought-Iron and Wrought-Steel Pipe and Tubing; H. J. Jaquith to L4 on Specifications for Sheeting; W. H. Bassett, Jr., and W. H. Gardner to C59 on Electrical Insulating Materials; W. S. Housel to A56 on Building Code Requirements for Excavations and Foundations; W. J. Krefeld to A59 on Building Code Requirements for Reinforced Gypsum Concrete; Theodore I. Coe to A62 on Coordination of Dimensions of Building Materials and Equipment; L. V. Foster (with H. E. Seemann as alternate) to Z38 on Standardization in the Field of Photography; Dean Harvey to C8 on Insulated Wire and Cables; C. B. Veal (with R. P. Anderson as alternate) to D9 on Standardization in the Field of Aeronautics.

Vice-President H. H. Morgan has been reappointed as the Society's representative on the Mechanical Standards Committee of A.S.A. for three years.

The need of cooperation in the work in the paper-testing field newly begun by A.S.T.M. through Committee D-6 on Paper and Paper Products with the older work in the same field by the Technical Association of the Pulp and Paper Industry (TAPPI), has led to the formation of a small joint committee between the two organizations, for the purpose of coordinating the activities of committees working along similar lines and of facilitating consideration in the one body of standards developed in the other. The Society's representatives are R. C. Griffin and L. C. Reid, chairman and secretary of Committee D-6. Mr. Reid is chairman of the joint committee.

The Society is cooperating with the Society of Automotive Engineers in the development of standards for rubber for automotive uses (exclusive of tires and tubes). A technical committee on this subject is being formed under the direction of Committee D-11 on Rubber Products, upon which the automotive and rubber industries will be well represented.

Max Hecht, chairman of Committee D-19 on Water for Industrial Uses, has been appointed as the Society's representative on the Feedwater Committee of the A.S.M.E. Boiler Code Committee.

L. M. Currie has been appointed to represent the Society on the Division of Engineering and Industrial Research, National Research Council, for a term of two years. He succeeds R. W. Crum.

An important development in the field of corrosion research is the formation of the American Coordinating Committee on Corrosion, announced in the A.S.T.M. BULLETIN for March, 1939, and discussed more fully in the current report of Committee E-9 on Research. The Society's representative on the Coordinating Committee is F. F. Farnsworth.

During the coming year the Society will cooperate with the Analytical Division of the American Chemical Society in a joint meeting during the 1940 Annual Meeting, featuring a symposium on chemical and physicochemical methods for examination of materials.

International Relations:

The program for the next Congress of the International Association for Testing

Materials, to be held in Munich in June, 1940, has been developed during the year by the Permanent Committee of I.A.T.M. A number of members of the Society have been invited to contribute papers on selected subjects, or to act as general or associate "reviewers" of assigned topics. Under the revised statutes of I.A.T.M., the entire responsibility for the Congress, including publication of the Congress Book, is being assumed by the Deutscher Verband für die Materialprüfungen der Technik. The Permanent Committee has disbanded the Study Commissions in existence prior to the 1937 Congress in London, but has reserved authority to appoint such new Commissions as may be appropriate, as for example in giving advice on properties and tests of materials to other international bodies.

N. L. Mochel has been appointed American member of I.S.A. Committee 17 on Iron and Steel, succeeding F. N. Speller.

Upon invitation from the British Joint Committee on Materials and Their Testing, the Society has suggested three American authors to contribute papers to the British Symposium on Testing of Heat Insulation Materials to be held in England next fall under the auspices of the British Joint Committee.

Working through the U. S. Chamber of Commerce, the Society is maintaining contacts with the American Chambers of Commerce and other American representatives in various foreign countries. Requests are often received for information on A.S.T.M. standards; the Index to Standards and other literature have accordingly been widely distributed with the offer of a complimentary copy of any specification requested by secretaries of American Chambers of Commerce and commercial attachés. The endeavor to increase foreign trade brings a demand for greater knowledge of American standards, and availability of A.S.T.M. standards in the offices of American representatives abroad is helpful to American business interests. There is some possibility that interest may be revived in the translation of a number of A.S.T.M. standards into foreign languages, especially for promotion of South American trade relations. A number of standards were thus translated and published in French and Spanish some fifteen or twenty years ago, both by private interests and by the United States Government.

Administrative:

Two vacancies occurred during the year in the membership of the Executive Committee, through the resignation due to ill health of Allen Rogers and the resignation due to change in business connections of G. E. Hopkins. These vacancies were filled by the appointment, respectively, of John R. Townsend, Materials Standards Engineer, Bell Telephone Laboratories, Inc., and Herbert J. Ball, Professor of Textile Engineering, Lowell Textile Institute. The terms of office extend to June, 1940.

Various appointments to administrative committees of the Society, to joint committees, and to committees of other organizations have been made by the Executive Committee and reported currently in the ASTM BULLETIN.

Respectfully submitted on behalf of the Executive Committee,

T. G. DELBRIDGE,
President.

C. L. WARWICK,
Secretary-Treasurer.

June, 1939.

REPORT OF COMMITTEE A-1

ON

STEEL

The standardization activities of Committee A-1 on Steel have been very intensive during the past year. This has been so primarily because of the desire to have the steel specifications in as satisfactory form as possible for the 1939 Book of A.S.T.M. Standards; also, several major projects under way for many months have come to fruition during the year, resulting in the proposing of several important new specifications or revised standards as described in this report.

Three series of meetings have been held during the year: in Atlantic City, N. J., June 27 to 29, 1938; the second in Philadelphia, Pa., January 25 and 26, 1939; and the third in Columbus, Ohio, March 6 and 7, 1939. Including subcommittee meetings, the number of sessions held during the year exceeded 40. All have been well attended with much constructive work resulting.

Since the 1938 annual meeting, 17 new members have been elected and 5 resignations accepted, the committee membership now totaling 226, of whom 105 are classified as producers, 94 as consumers, and 27 as general interest members.

During the year several of the subcommittees have appointed sections to handle particular problems. In one case in particular this has resulted in adding as new members of the committee several technical men concerned with the field of spring wire. Subcommittee IV on Spring Steel and Steel Springs has organized a new section to undertake specification work in this field under the chairmanship of F. P. Zimmerli, Barnes-Gibson-Raymond, Division of Associated Spring Corp. A new section on welding fittings for high-temperature service headed by J. J. Kanter, Crane Co., has been organized by Subcommittee XXII and will function permanently in this field. In the discussion of subcommittee activities later in this report, mention is made of the work of other sections.

It is the sustained interest and coöperation of the members and chairmen of these various sections and subcommittees which has made possible what is considered a very constructive year by the steel committee.

Losses by Death.—During the year, Committee A-1 has lost by death several members, including J. S. Bradshaw, R. H. Irons, J. R. Page, L. A. Prescott, and J. B. Young. The committee records its sincere appreciation of their generous services. Of these men, one had an outstanding record of service on behalf of the committee. He had been a member of Committee A-1 for 26 years, was vice-chairman from 1924 to 1926, and chairman for three terms (1926 to 1932). In addition, he had been active on numerous subcommittees and contributed unselfishly of his time and energy in furthering the work of this committee. In deep appreciation of his efforts and to pay tribute to him, the committee has adopted the following resolution:

Resolution on the Death of J. Bertram Young

1876–1938

In the death on July 30, 1938, of J. Bertram Young, Engineer of Tests, Reading Co., Reading, Pa., the members of Committee A-1 on Steel have lost a respected and understanding co-worker. As a member of the committee since 1912 and an officer for many years, he took part in many important activities of the committee and contributed greatly to the progress it has made. One of the most loyal members of the committee, he was always ready to undertake work in its behalf.

During his tenure of office (vice-chairman, 1924 to 1926; chairman, 1926 to 1932) many specifications of importance to manufacturers and users of steel were brought to successful completion and much other work was begun.

As an officer of the committee, his acts were at all times based on a thorough understanding of problems confronting the various interests represented in its membership, supported by sound technical knowledge.

As a committee member and a representative not only of his own company but of railroads collectively as a great consuming interest with whose needs he was familiar, his actions and opinions were always tempered with an understanding view of the producers' problems as well.

In all his official and personal contacts, Mr. Young exhibited a kindly personality which was basic in his character—a personality which made for him a host of friends in the committee and throughout the Society. Through friendly personal acts he endeared himself to a great number of his fellow committeemen.

In meeting assembled, Committee A-1 on Steel pays homage to Mr. Young as an outstanding engineer and as a gentleman, and now records its appreciation for his extensive and long-time services as an officer and member.

Reaffirmation of Specifications.—Practically all of the large number of specifications under the jurisdiction of the committee have been reviewed to determine whether or not they are up to date, and certain comments on various standards that are considered up to date but in which no revisions are recommended appear later in this report under the discussion of subcommittee activities. In the case of one group's specifications, in the field of rail and track fastenings, a vote has been taken in the group and in Committee A-1 reaffirming these specifications. Accordingly, it is taking advantage of the new procedure by which a note indicating this action will appear on the specifications. These items are listed in Table I and later in this report in the discussion of the work of Subcommittee I.

Editorial Study.—Resetting in the new format of most of the 100 specifications in the charge of the committee has entailed detailed editorial study. The various subcommittee chairmen and other members of the committee have cooperated with the Society staff in this work. The assistance of J. O. Leech has been invaluable in these studies. A number of inconsistencies have been eliminated and in general the editorial changes proposed are in the interests of clarification and simplification.

Tentative Standards and Revisions Approved During the Past Year.—Subsequent to the 1938 annual meeting, Committee A-1 on Steel presented to the Society on August 25, 1938, through Committee E-10 on Standards the recommendations listed below, all of which were accepted:[1]

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[1] In submitting these recommendations to Committee E-10 on Standards, Committee A-1 reported the following results of the letter ballot vote of a total of 128 ballots returned from a committee membership of 211: A 210 - 38 T, affirmative 74, negative 1, ballots marked "not voting" 53; A 209 - 38 T, affirmative 76, negative 0, ballots marked "not voting" 52; A 211 - 38 T, affirmative 69, negative 1, ballots marked "not voting" 58; A 83 - 38 T, affirmative 74, negative 0, ballots marked "not voting" 54; A 192 - 36 T, affirmative 70, negative 0, ballots marked "not voting" 57; A 194 - 38 T, affirmative 73, negative 0, ballots marked "not voting" 55; A 134 - 36, affirmative 69, negative 1, ballots marked "not voting" 58; A 139 - 36, affirmative 74, negative 0, ballots marked "not voting" 54; A 15 - 35, affirmative 74, negative 0, ballots marked "not voting" 54; A 160 - 36, affirmative 74, negative 0, ballots marked "not voting" 54.

Tentative Specifications for:

Medium Carbon Seamless Steel Boiler and Superheater Tubes (A 210 – 38 T),

Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 209 – 38 T),

Spiral Welded Steel or Iron Pipe (A 211 – 38 T),

Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 – 38 T) which are a revision of and supersede the corresponding Standard Specifications A 83 – 36 which were by simultaneous action withdrawn,

Revision of Tentative Specifications for:

Seamless Steel Boiler Tubes for High-Pressure Service (A 192 – 36 T),

Carbon and Alloy-Steel Nuts for Bolts for High-Pressure and High-Temperature Service to 1100 F. (A 194 – 38 T),

Tentative Revision of Standard Specifications for:

Electric-Fusion-Welded Steel Pipe (Sizes 30 in. and Over) (A 134 – 36),

Electric-Fusion-Welded Steel Pipe (Sizes 8 in. to but not Including 30 in.) (A 139 – 36),

Billet-Steel Concrete Reinforcement Bars (A 15 – 35), and

Axle-Steel Concrete Reinforcement Bars (A 160 – 36).

The six tentative specifications and the four tentative revisions of standards appear in the 1938 *Proceedings*.[2]

The extent of use of the medium-carbon grade of material previously covered as grade C in the Standard Specifications for Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 – 36) as well as the desirability of embodying certain modifications and additional requirements led to separate specifications for this grade of material. The withdrawal from Specifications A 83 of grade C was accompanied by other important changes, particularly the method of indicating wall thickness by decimals in place of B.w.g. and fractions; also permissible variations for wall thickness and weight are now indicated in percentages rather than by the dual system which existed previously. Revised tables of permissible variations for cold-drawn tubes were included for the sake of completeness and a restriction limiting the allowable eccentricity in any one tube.

Concurrently with the changes in the Specifications for Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 – 38 T), the Specifications for Seamless Steel Boiler Tubes for High-Pressure Service (A 192 – 36 T) were revised embodying the appropriate modifications described in the preceding paragraph.

The new specifications for carbon-molybdenum seamless and boiler superheater tubes and for spiral welded steel or iron pipe met definite needs for standardized requirements for these materials. In each case close cooperation of consumers and makers has resulted in the establishment of satisfactory requirements. In the case of spiral pipe, there are three types in rather widespread use. Because it is not possible to cover completely in a single specification all types of this kind of pipe, the new specification covers material less than $\frac{3}{16}$ in. in thickness, and tentative revisions were set up with the thought in mind that they would be adopted in 1939 in the two existing Standard Specifications for Electric-Fusion-Welded Steel Pipe (sizes 30 in. and over) (A 134 – 36) and Standard Specifications for Electric-Fusion-Welded Steel Pipe (sizes 8 in. to but not Including 30 in.) (A 139 – 36) to cover spiral pipe in heavier wall thicknesses.

Proposed changes in the reinforcing bar specifications (A 15 and A 160) intended to be adopted in 1939 will remove overlapping requirements and also overcome a source of confusion and misinterpretation in the manufacture and use of this material.

The modifications made in the Specifications for Carbon and Alloy-Steel Nuts for Bolts for High-Pressure and

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[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 543, 550, 557, 531, 537, 560, 1309, 1310 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 78, 85, 107, 66, 72, 116, 1675, 1676.

High-Temperature Service to 1100 F. (A 194 – 38 T) met the demand for a low-carbon sulfur nut, and also by changes in chemical composition provided that materials of similar composition covered in other specifications for high-temperature service can be used in fabrication of the nuts.

Revisions in Permissible Variations:

Prior to the January meeting of the committee, there was referred by letter for comment and consideration to some 50 members, including general interests, consumers and producers, a suggestion that there be established in one place, either as a specification or a standard practice, tolerances for rolled steel products, and with this the further suggestion that there be eliminated from the specifications the existing tables, references to be included in each of the specifications involved to the separate specifications for tolerances. The proposal also included that there be given in the tolerance specification the various permissible variations established by the Association of American Steel Manufacturers Technical Committees covering shapes, both structural and bar size. At the January meetings there was considerable discussion in several subcommittees and in the Advisory Committee with no conclusive decision being reached, opinions from individuals and from subcommittees being about evenly divided on the merits of the proposal. Further discussion at the meeting of the Advisory Committee in Columbus resulted in the matter being tabled, it being the general feeling that considerable time would be entailed in such a change and since there was no unanimity of opinion, no action should be taken at present.

It is desirable that the tables of permissible variations appearing in so many of the steel specifications be in line with current practice. Accordingly, relatively recent changes in the manufacturers' standard practice as set up by the Association of American Steel Manufacturers Technical Committees will result in modifications in a number of tables in the steel specifications involving the tables of permissible variations as follows: permissible variations of plates ordered to weight, permissible overweights of plates ordered to thickness, permissible variations over ordered thickness of plates over 2 in. in thickness, permissible variations in the sizes of rounds and squares, hexagons, flats, bar-size angles, tees, zees and channels. A number of the changes, particularly in the plate tables, have resulted from a difference in commercial distinction established between plates and sheets. In other cases tables have been extended to cover larger dimensioned materials. While in most cases, particularly for plates, tolerances have not been modified, in some involving bars and related shapes the tolerances have been narrowed. In the Appendix are given the latest tables of permissible variations which will be included in the steel specifications, together with a listing of those standards in which the revised tables will appear. When the steel specifications are published in the 1939 Book of Standards only the sizes covered by the scope of the respective specifications will be included in the tolerance tables.

While these changes are considered primarily of an editorial nature, letter ballots in the appropriate subcommittees and in the main committee have been taken, resulting in a practically unanimous affirmative vote.

For convenience, the recommendations of the committee affecting its standard and tentative specifications are listed below in summarized form with an analysis of the letter ballot given in Table I. Certain of these recommendations are referred to further in the discussion of subcommittee activities.

I. NEW TENTATIVE STANDARDS

The committee recommends that the following proposed tentative specifications be accepted for publication as tentative:[3]

Proposed Tentative Specifications for:

Seamless Alloy-Steel Boiler and Superheater Tubes,
Electric-Resistance-Welded Steel Heat-Exchanger and Condenser Tubes,
Carbon-Steel Castings Suitable for Fusion Welding for Miscellaneous Industrial Uses,
Carbon-Steel Castings Suitable for Fusion Welding for Service at Temperatures up to 850 F., and
Alloy-Steel Castings Suitable for Fusion Welding for Service at Temperatures from 750 to 1100 F.

II. NEW STANDARDS

The committee recommends the following specifications[4] for immediate adoption as standard and accordingly asks for the necessary nine-tenths vote:

Proposed Specifications for:

Steel for Bridges and Buildings (A 7 - 39), and
High Tensile Strength Carbon-Silicon Steel Plates for Pressure Vessels (Plates 4½ in. and Under in Thickness).

The proposed Specifications for Steel for Bridges and Buildings (A 7 - 39) are a consolidation of the existing Specifications for Steel for Bridges (A 7 - 36; A.S.A. G18 - 1936) and for Steel for Buildings (A 9 - 36; A.S.A. G19 - 1936).

The proposed Specifications for High Tensile Strength Carbon-Steel Plates for Pressure Vessels (Plates 4½ in. and Under in Thickness) are a consolidation of the Specifications for High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates 2 in. and Under in Thickness) (A 149 - 38) and for High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates over 2 to 4½ in., Inclusive, in Thickness) (A 150 - 38).

Further explanation of these proposed consolidated standards appears later in this report under the heading "Activities of Subcommittees."

III. REVISIONS OF TENTATIVE STANDARDS

The committee recommends that the following tentative specifications be revised, as indicated in the Appendix, and continued as tentative:

Tentative Specifications for:

Heat-Treated Carbon- and Alloy-Steel Track Bolts (A 183 - 36 T),
High-Strength Structural Rivet Steel (A 195 - 36 T),
Seamless Steel Boiler Tubes for High-Pressure Service (A 192 - 38 T) editorial change, and
Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A 206 - 38 T).

IV. TENTATIVE REVISIONS OF STANDARDS

The committee recommends that the revisions, as given in the Appendix, of the Standard Specifications for Boiler and Firebox Steel for Locomotives (A 30 - 38) be published as tentative for one year before they are referred to letter ballot of the Society for adoption as standard.

V. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative specifications be referred to letter ballot of the Society for adoption as standard with revisions in one of the specifications listed, as given in detail in the Appendix:

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[3] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

[4] These specifications were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

Tentative Specifications for:

High-Carbon-Steel Joint Bars (A 5 - 36 T),[5]
Quenched Carbon-Steel Joint Bars (A 49 - 36 T),[5]
Normalized Quenched-and-Tempered Alloy-Steel Forgings (A 63 - 38 T),[6]
One-Wear and Two-Wear Wrought Steel Wheels (A 186 - 36 T),[7] (as revised),
Carbon-Steel Castings for Miscellaneous Industrial Uses (A 27 - 36 T),[7]
Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 - 37 T),[8]
Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 37 T),[8]
Low-Carbon-Nickel Steel Plates for Boilers and Other Pressure Vessels (A 203 - 37 T),[8] and
Carbon and Alloy-Steel Nuts for Bolts for High-Pressure and High-Temperature Service to 1100 F. (A 194 - 38 T).[9]

VI. ADOPTION OF REVISIONS OF STANDARDS

The committee recommends that revisions previously published as tentative[10] in the Standard Specifications for Iron and Steel Chain (A 56 - 30) be referred to letter ballot of the Society for adoption as standard.

Revisions previously published as tentative[10] and revisions for immediate adoption as given in the Appendix are recommended for reference to letter ballot of the Society for adoption as standard in the following:

Standard Specifications for:

Alloy-Steel Bolting Material for High-Temperature Service (A 96 - 33; A.S.A. G 17.2 - 1934),
Alloy-Steel Castings for Valves, Flanges and Fittings for Service at Temperatures from 750 to 1100 F. (A 157 - 36),
Forged or Rolled Steel Pipe Flanges for High-Temperature Service (A 105 - 36; A.S.A. G 17.3 - 1936),
Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for Service at Temperatures from 750 to 1100 F. (A 182 - 36), and
Lap-Welded and Seamless Steel Pipe for High-Temperature Service (A 106 - 36; A.S.A. B 36.3 - 1936).

Revisions for immediate adoption as given in the Appendix are recommended for reference to letter ballot of the Society for adoption as standard in the following; the committee asking for the necessary nine-tenths vote:

Standard Specifications for:

Open-Hearth Carbon-Steel Rails (A 1 - 36),
Carbon-Steel Bars for Railway Springs (A 14 - 27),
Silico-Manganese-Steel Bars for Railway Springs (A 59 - 27),
Chrome-Vanadium-Steel Bars for Railway Springs (A 60 - 27),
Carbon-Steel Bars for Railway Springs with Special Silicon Requirements (A 68 - 36),
Helical Steel Springs for Railways (A 61 - 16), revised as appended hereto,[11]
Heat-Treated Carbon-Steel Helical Springs (A 125 - 33), revised as appended hereto,[11]
Elliptical Steel Springs for Railways (A 62 - 16), revised as appended hereto,[11]
Heat-Treated Steel Elliptical Springs (A 147 - 35), revised as appended hereto,[11]
Multiple-Wear Wrought Steel Wheels (A 57 - 36),
Steel Tires (A 26 - 16) (in the form of new specifications appended),[11]
Open-Hearth Iron Plates of Flange Quality (A 129 - 33),
Steel Plates of Flange and Firebox Qualities for Forge Welding (A 89 - 33),
Carbon-Silicon-Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers

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[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, pp. 579, 583 (1936); also 1938 Book of A.S.T.M. Tentative Standards, pp. 22, 25.

[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 586 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 45.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, pp. 592, 598 (1936); also 1938 Book of A.S.T.M. Tentative Standards, pp. 52, 58.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, pp. 601, 608, 577 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 92, 99, 5.

[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 560 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 116.

[10] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1315, 1310, 1311, 1313 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1681, 1676, 1677, 1679.

[11] These specifications were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

and Other Pressure Vessels (A 201 - 38), and

Boiler Rivet Steel and Rivets (A 31 - 36).[12]

Revisions approved for publication as tentative by Committee E-10 on Standards in August, 1938, are recommended to be approved for reference to letter ballot of the Society for adoption, in the following:

Standard Specifications for:

Billet-Steel Concrete Reinforcement Bars (A 15 - 35; A.S.A. A 50.1 - 1936),

Axle-Steel Concrete Reinforcement Bars (A 160 - 35),

Electric-Fusion-Welded Steel Pipe (Sizes 30 in. and Over) (A 134 - 36; A.S.A. B 36.4 - 1936), and

Electric-Fusion-Welded Steel Pipe (Sizes 8 in. to but not Including 30 in.) (A 139 - 36; A.S.A. B 36.9 - 1936).

The committee asks for the necessary nine-tenths vote at the annual meeting in order that all revisions not published previously as tentative and those approved by Committee E-10 on Standards last August may be referred to Society letter ballot.

VII. WITHDRAWAL OF STANDARDS AND TENTATIVE STANDARDS

The following specifications are recommended for withdrawal:

Standard Specifications for:

Steel for Buildings (A 9 - 36; A.S.A. G 19 - 1936),

Quenched-and-Tempered Alloy-Steel Axles, Shafts and Other Forgings for Locomotives and Cars (A 63 - 36),

Quenched-and-Tempered Carbon-Steel Axles, Shafts and Other Forgings for Locomotives and Cars (A 19 - 36),

High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates 2 in. and Under in Thickness) (A 149 - 38), and

High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates over 2 to 4½ in., Inclusive, in Thickness) (A 150 - 38).

Tentative Specifications for:

Carbon-Steel Forgings for Locomotives (A 20 - 31 T).

Comments on the withdrawal of these specifications appear later in this report under the Activities of Subcommittees. Many of the requirements given in the specifications are being incorporated into other specifications resulting from consolidation.

The recommendations appearing in this report have been referred to letter ballot of the committee which consists of 226 members with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Certain features of the committee's work are discussed below, grouped in the order of the respective subcommittees responsible.

Subcommittee I on Steel Rails and Accessories (E. F. Kenney, chairman).—The revisions proposed for immediate adoption in the Specifications for Open-Hearth Carbon-Steel Rails (A 1 - 36) are recommended to bring the requirements in line with similar specifications of the American Railway Engineering Assn. and those in the Tentative Specifications for Heat-Treated Carbon and Alloy-Steel Track Bolts (A 183 - 36 T) are intended as a clarification.

Seven of the standards in the charge of this subcommittee have remained for six or more years without revision. Accordingly, the committee has reviewed these, reaffirming them by letter ballot and it recommends taking advantage of the procedure to be established by which a notice of the reaffirmation will appear on them. The specifications are as follows:

Manufacture of Open-Hearth Steel Girder Rails of Plain, Grooved and Guard Types (A 2 - 27),

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[12] On the recommendation of Committee A-1 on Steel, the Executive Committee at its October, 1939, meeting approved postponement of the adoption of the revision in Standard A 31 which had been approved by Society letter ballot, September 15, 1939. The revision will continue to be published as tentative, as the committee plans to prepare requirements for bending and flattening properties before having the changes incorporated in the specifications.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Alloy Steel Boiler and Superheater Tubes	85	1	76
Spec. for Electric Resistance Welded Steel Heat-Exchanger and Condenser Tubes	81	0	81
Spec. for Carbon-Steel Castings for Miscellaneous Industrial Uses Suitable for Fusion Welding	100	3	59
Spec. for Carbon-Steel Castings Suitable for Fusion Welding for Service at Temperatures up to 850 F.	86	3	73
Spec. for Alloy-Steel Castings Suitable for Fusion Welding for Service at Temperatures from 750 to 1100 F.	87	1	74
II. NEW STANDARDS			
Spec. for Steel for Bridges and Buildings (A 7 - 39)	99	0	63
Spec. for High Tensile Strength Carbon-Steel Plates for Pressure Vessels (Plates 4½ in. and Under in Thickness)	83	0	79
III. REVISIONS OF TENTATIVE STANDARDS			
Spec. for Heat-Treated Carbon- and Alloy-Steel Track Bolts (A 183 - 36 T)	53	1	77
Spec. for High-Strength Structural Rivet Steel (A 195 - 36 T)	77	0	54
Spec. for Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A 206 - 38 T)	71	0	60
IV. TENTATIVE REVISIONS OF STANDARDS			
Spec. for Boiler and Firebox Steel for Locomotives (A 30 - 38)	82	4	76
V. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for High-Carbon-Steel Joint Bars (A 5 - 36 T)	55	0	76
Spec. for Quenched Carbon-Steel Joint Bars (A 49 - 36 T)	55	0	76
Spec. for Normalized Quenched-and-Tempered Alloy-Steel Forgings (A 63 - 38 T), as revised	77	2	54
Spec. for One-Wear and Two-Wear Wrought Steel Wheels (A 186 - 36 T), as revised	52	0	79
Spec. for Carbon-Steel Castings for Miscellaneous Industrial Uses (A 27 - 36 T)	107	3	52
Spec. for Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 - 37 T)	71	0	57
Spec. for Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 37 T)	73	0	55
Spec. for Low-Carbon-Nickel Steel Plates for Boilers and Other Pressure Vessels (A 203 - 37 T)	65	2	64
Spec. for Carbon and Alloy-Steel Nuts for Bolts for High-Pressure and High-Temperature Service to 1100 F. (A 194 - 38 T)	69	2	60
VI. ADOPTION OF REVISIONS OF STANDARDS			
Spec. for Open-Hearth Carbon-Steel Rails (A 1 - 36), immediate adoption	50	0	81
Spec. for Carbon-Steel Bars for Railway Springs (A 14 - 27), immediate adoption	82	0	80
Spec. for Silico-Manganese-Steel Bars for Railway Springs (A 59 - 27), immediate adoption	78	0	84
Spec. for Chrome-Vanadium-Steel Bars for Railway Springs (A 60 - 27), immediate adoption	77	0	85
Spec. for Carbon-Steel Bars for Railway Springs with Special Silicon Requirements (A 68 - 36), immediate adoption	76	0	86
Spec. for Helical Steel Springs for Railways (A 61 - 16), immediate adoption	73	1	88
Spec. for Heat-Treated Carbon-Steel Helical Springs (A 125 - 33), immediate adoption	71	1	90
Spec. for Elliptical Steel Springs for Railways (A 62 - 16), immediate adoption	72	0	90
Spec. for Heat-Treated Steel Elliptical Springs (A 147 - 35), immediate adoption	70	0	92
Spec. for Billet-Steel Concrete Reinforcement Bars (A 15 - 35; A.S.A. A 50. 1 - 1936)	58	2	71
Spec. for Axle-Steel Concrete Reinforcement Bars (A 160 - 36)	59	1	71
Spec. for Multiple-Wear Wrought Steel Wheels (A 57 - 36), immediate adoption	52	0	79
Spec. for Steel Tires (A 26 - 16), immediate adoption	47	0	84
Spec. for Electric-Fusion-Welded Steel Pipe (Sizes 30 in. and Over) (A 134 - 36; A.S.A. B 36.4 - 1936)	86	0	76
Spec. for Electric-Fusion-Welded Steel Pipe (Sizes 8 in. to but not Including 30 in.) (A 139 - 36; A.S.A. B 36.9 - 1936)	86	0	76
Spec. for Boiler Rivet Steel and Rivets (A 31 - 36), immediate adoption[12]	83	2	77
Spec. for Open-Hearth Iron Plates of Flange Quality (A 129 - 33), immediate adoption	61	2	68

TABLE I.—*Concluded*

Items	Affirmative	Negative	Ballots Marked "Not Voting"
Spec. for Steel Plates of Flange and Firebox Qualities for Forge Welding (A 89 - 33), immediate adoption	61	3	67
Spec. for Carbon-Silicon-Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 - 38), immediate adoption	65	1	65
Spec. for Alloy-Steel Bolting Material for High-Temperature Service (A 96 - 33; A.S.A. G 17.2 - 1934)	66	1	64
Spec. for Alloy-Steel Castings for Valves, Flanges and Fittings for Service at Temperatures from 750 to 1100 F (A 157 - 36), immediate adoption	74	1	56
Spec. for Iron and Steel Chain (A 56 - 30)	52	0	110
Spec. for Forged or Rolled Steel Pipe Flanges for High-Temperature Service (A 105 - 36; A.S.A. G 17.3 - 1936), immediate adoption	70	0	61
Spec. for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for Service at Temperatures from 750 to 1100 F. (A 182 - 36), immediate adoption	71	0	61
Spec. for Lap-Welded and Seamless Steel Pipe for High-Temperature Service (A 106 - 36; A.S.A. B 36.3 - 1936), immediate adoption	73	1	57
VII. WITHDRAWAL OF STANDARDS AND TENTATIVE STANDARDS			
Spec. for Steel for Buildings (A 9 - 36; A.S.A. G 19 - 1936)	99	0	63
Spec. for Quenched-and-Tempered Alloy-Steel Axles, Shafts and Other Forgings for Locomotives and Cars (A 63 - 36)	77	2	54
Spec. for Quenched-and-Tempered Carbon-Steel Axles, Shafts and Other Forgings for Locomotives and Cars (A 19 - 36)	120	4	58
Spec. for Carbon-Steel Forgings for Locomotives (A 20 - 31 T)	120	4	58
Spec. for High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates 2 in. and Under in Thickness) (A 149 - 38)	83	0	79
Spec. for High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates over 2 to 4½ in., Inclusive, in Thickness) (A 150 - 38)	83	0	79
VIII. REAFFIRMATION OF SPECIFICATIONS			
Spec. for Manufacture of Open-Hearth Steel Girder Rails of Plain, Grooved and Guard Types (A 2 - 27)	45	0	86
Spec. for Low-Carbon-Steel Splice Bars (A 3 - 33)	47	0	84
Spec. for Medium-Carbon-Steel Splice Bars (A 4 - 14)	47	0	84
Spec. for Soft Steel Track Spikes (A 65 - 33)	48	0	83
Spec. for Steel Tie Plates (A 67 - 33)	47	0	84
Spec. for Low-Carbon-Steel Track Bolts (A 76 - 33)	48	0	83
Spec. for Steel Screw Spikes (A 66 - 33)	46	0	85

Low-Carbon-Steel Splice Bars (A 3 – 33),
Medium-Carbon-Steel Splice Bars (A 4 – 14),
Soft Steel Track Spikes (A 65 – 33),
Steel Tie Plates (A 67 – 33),
Low-Carbon-Steel Track Bolts (A 76 – 33), and
Steel Screw Spikes (A 66 – 33).

Subcommittee II on Structural Steel for Bridges, Buildings and Rolling Stock (F. H. Frankland, chairman).—The reduction in the tensile range in the Tentative Specifications for High-Strength Structural Rivet Steel (A 195 – 36 T) as given in the Appendix is believed will result in material better suited to the requirements. The original tensile values were based upon the steel in the "as-rolled" condition, whereas the rivet stock required in this specification must be annealed.

Probably the most important and far reaching change in this report is the one involving the consolidation of the specifications for steel for bridges (A 7) and steel for buildings (A 9). These new specifications, to carry the designation A 7, are appended.[13] It provides for the following changes, in brief: The phosphorus limit for basic open-hearth steel for use in buildings is to be reduced from 0.06 to 0.04 per cent as required for bridges, and it will place the same sulfur limit on material for buildings as now required for bridges, namely, 0.05 per cent. The elongation requirement for steel for buildings will be increased from the present minimum requirement in 8 in. of a figure represented by 1,400,000 divided by tensile strength, to 1,500,000 divided by tensile strength, and the bend test for this material will be somewhat more restrictive, so that both the elongation and bend test will meet the requirements for these properties as now provided in the Specifications for Steel for Bridges (A 7 - 36).

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[13] These specifications were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

Improvements in manufacturing processes and other factors have made it possible for producers economically to furnish the higher grade steel provided in the bridge specifications to be used in building and other construction. In recent months there has been a markedly increased tendency in this direction. Accordingly it seems desirable from the manufacturers standpoint to take cognizance of the situation by enlarging the scope of the specifications. From the standpoint of the consumers, the change should be welcomed.

Requirements for structural bolts are provided for in the new specifications.

During the year there has been discussion of a possible combination embodying the requirements of the Standard Specifications for Mild Steel Plates (A 10 - 34) and the Standard Specifications for Steel Plates of Structural Quality for Forge Welding (A 78 - 33), but the matter needs further consideration.

Subcommittee IV on Spring Steel and Steel Springs (C. T. Edgerton, chairman).—Detailed studies initiated primarily from the standpoint of editorial improvement indicated the desirability of a number of changes in eight of the nine specifications covering springs and bars for springs. The intensive work on these revisions has been handled by a special section headed by T. R. Weber, American Locomotive Co., Railway Steel-Spring Division. The changes clarify a number of points and bring about a desirable uniformity of expression for similar requirements. The four specifications for springs, A 61, A 125, A 62, and A 149 are submitted in their revised form as complete specifications.[11] Changes in the bar specifications, A 14, A 59, A 60, and A 68 are noted in the Appendix, even though with one exception they might be considered as editorial.

One very important activity of the subcommittee, initiated during the year, is the formation of a new section headed by Mr. Franz Zimmerli, Barnes-Gibson-Raymond Division, Associated Spring Corp., to develop standardized requirements for the material known as music wire. There are no standardized specifications for any of the various kinds of material used in the manufacture of wire springs. Accordingly, a study of the entire field will eventually be made. In order that the section will be quite adequate for this task, a number of new members have been secured to cooperate in this work, representing interests concerned with the production or use of spring wire. The section for the present plans to concentrate its work on round spring wire exclusive of round spring grades. While the problems confronting this section are many, it is expected that definite recommendations can be made in the near future for certain materials.[14]

Pending further study, possible revision or withdrawal of the Standard Specifications for Carbon-Steel Bars for Vehicle and General Purpose Springs (A 58 - 27) is being considered, but no action is proposed in connection with these specifications at this time.

Subcommittee VI on Steel Forgings and Billets (W. M. Barr, chairman).—Intensive work by a special section headed by P. E. McKinney resulted in proposed revised specifications for carbon-steel forgings to consolidate into one document requirements for all grades of carbon-steel forgings covered in three existing Specifications A 18, A 19 and

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[14] See Editorial Note, p. 79.

A 20. Objections were raised, however, to the proposed requirements for physical properties. As a result, new proposed tentative specifications for carbon-steel forgings have been drafted and will be submitted to the Society through Committee E-10 on Standards. The existing Standard A 18 – 30 will be continued, but Standard Specifications A 19 and A 20 are to be withdrawn.[14]

A companion section headed by J. H. Higgins has developed drafts for proposed specifications for alloy-steel forgings to cover in a consolidated specification all forgings of alloy steel now given in Specifications A 133, A 18, and A 63. It is expected action will be taken within the year to approve these new specifications for submission to the Society for publication as tentative, at the same time withdrawing the existing specifications listed. During the period that the proposed consolidated alloy-steel specifications are tentative, the committee feels it desirable to retain the Tentative Specifications for Normalized Quenched-and-Tempered Alloy-Steel Forgings (A 63 – 38 T) and is taking action to recommend the adoption of the latter as standard after deletion of the section on proof tests and the appendix relating to this test.

Two other specifications were reviewed by the subcommittee: the Standard Specifications for Carbon-Steel Car and Tender Axles (A 21 – 36) are essentially special specifications embodying tests which are not applicable to forgings other than axles and should stand without change; likewise no recommendations for changes in the Standard Specifications for Carbon-Steel and Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 17 – 29) are being made.

Subcommittee VII on Steel Wheels and Tires (R. W. Steigerwalt, chairman).—The Standard Specifications for Steel Tires (A 26 – 16) have not been revised since 1916, but recommended changes which have been developed will bring them up to date and cover all requirements and practices now used by the Association of American Railroads. The changes in substance and editorial modifications have been incorporated in the revised specifications which are recommended for continuation as standard.

With the adoption of the recommended revisions, as given in the Appendix, in the Standard Specifications for Multiple-Wear Wrought Steel Wheels (A 57 – 36) and in the Tentative Specifications for One-Wear and Two-Wear Wrought Steel Wheels (A 186 – 36 T) the subcommittee believes all of its specifications for steel wheels and tires will be up to date and in line with current practice. A number of editorial changes including modified tables itemizing permissible variations, a clearer type of illustration, and other corresponding changes should improve the utility of the specifications.

Subcommittee VIII on Steel Castings (W. C. Hamilton, chairman).—This subcommittee has reviewed the Standard Specifications for Austenitic Manganese-Steel Castings (A 128 – 33) which have remained unchanged since 1933. Since no suggestions other than of an editorial nature have been received, it is recommended that they continue without change in substance. The Tentative Specifications for Carbon-Steel Castings for Miscellaneous Industrial Uses (A 27 – 36 T), widely used in many branches of industry, have been tentative for three years and the requirements have proved generally acceptable. Accordingly, their adoption as standard at this time seems logical.

The subcommittee has been cognizant of a rapidly growing interest in the subject of welding castings and to meet the need for standardized requirements, including maximum carbon limits, has developed the proposed new Tentative Specifications for Carbon-Steel Castings for Miscellaneous Industrial Uses Suitable for Fusion Welding.[15] The subcommittee recognizes that when additional information is obtained on chemical limitations, including manganese, carbon, and other elements, it may be found necessary to recommend changes in the specifications. Very recent developments indicate the desirability of a standard covering low-alloy-steel castings for fusion welding, and it is anticipated work will begin soon in drafting requirements.

Subcommittee IX on Steel Tubing and Pipe (T. G. Stitt, chairman).—With over twenty specifications for various types and grades of pipe and tubing in its immediate charge, Subcommittee IX covers an extremely active field. Several different sections which have been responsible for parts of the program of work have achieved considerable success during the year. In addition to its recommendations submitted to Committee E-10 on Standards in August, referred to earlier in this report, several other important matters are recommended for action at the annual meeting. These include two proposed new specifications, under development for some time, covering alloy-steel boiler and superheater tubes and electric-resistance-welded steel heat-exchanger and condenser tubes. Revisions providing for the inclusion of the heavier weights of spiral welded steel and iron pipe are recommended for adoption as standard in the two specifications for electric-fusion-welded steel pipe A 134 – 36 and A 139 – 36.

When the scope of the Specifications for Seamless Steel Boiler Tubes for High-Pressure Service (A 192 – 38 T) was extended to include tubes of small diameter, no provision was made in the marking clause for a separate type of marking for tubes $1\frac{1}{4}$ in. in outside diameter and smaller, and accordingly the editorial change in these specifications set forth in the Appendix is being made.

At the present time, the committee has under way certain series of tests including the study of hydrostatic test requirements in its specifications; also hardness tests in which readings are to be taken on the outer and inner surfaces, as well as the core of tubular material.

The committee has been concerned for some time with the lack of provision for adequate pipe and tubular test specimens in the Standard Methods of Tension Testing of Metallic Materials (E 8 – 36). It is felt that such requirements should appear in these methods rather than to incorporate separate sections in a large number of standards for particular pipe products. Accordingly, the committee is urging Committee E-1 on Methods of Testing to take action on proposals recently made to correct this situation.

New work is constantly confronting the committee as different types of pipe and tubular products come into commercial demand. One example of this is the desirability of having standard requirements for electric-resistance-welded steel boiler tubes for high-pressure service. It is expected that a draft recommendation will be forthcoming in the near future.

Subcommittee XI on Boiler Steels (E. J. Edwards, chairman).—The Specifications for Open-Hearth Iron Plates of Flange Quality (A 129 – 33), which have remained unchanged for six years, were discussed at a meeting of the committee, the consensus being reached that while the major requirements are satisfactory, it is desirable to delete the match-marking requirements. No other change is recommended at this time. Demand for standardized requirements for higher strength boiler rivet steels was at first to be met by drafting new specifications, but further consideration indicated the desirability of incorporating the one grade that is in rather wide usage, namely, a 58,000 to 68,000 psi. tensile strength grade in the present Specifications for Boiler Rivet Steel and Rivets (A 31 - 36). Accordingly, this proposal is being made. For details, see the Appendix.

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[15] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

Consolidated specifications embodying requirements for high tensile strength carbon-silicon steel plates for pressure vessels covered in the two existing Standard Specifications A 149 and A 150, have been completed and are being recommended for adoption as standard. No essential substance changes are incorporated in the combined specifications. It is possible the committee may recommend shortly the consolidation of two other specifications covering Carbon-Steel Plates (A 70) and Steel Plates of Flange and Firebox Qualities (A 89). While certain objections were raised at the March meeting, a subsequent letter ballot vote indicates an overwhelming opinion in favor of consolidation. The suggestion that a limitation be placed on incidental copper content for firebox material in the Specifications for Boiler and Firebox Steel for Locomotives (A 30 - 38) has been made by the railroad interests and the tentative revision detailed in the Appendix is intended eventually to meet this demand.

One of the major problems still before the committee is the drafting of satisfactory requirements for the numerous classes of low-alloy steel plate material for boiler and pressure vessel work. While there are four existing specifications for different alloys, including one tentative standard the latter covering low-carbon-nickel steel plates for boilers and other pressure vessels (A 203 - 37 T), now recommended for adoption as standard, the possibility of consolidated specifications is being given further thought. Originally it was hoped one specification with various classes of steel might be developed but this idea was temporarily abandoned. However, the special section headed by L. P. McAllister is considering the numerous ramifications involved, and certain recommendations are hoped for soon.

Subcommittee XIII on Methods of Physical Tests (L. H. Fry, chairman).—This subcommittee has held three interesting and well-attended meetings during the year, at each of which there has been consideration of various questions affecting determination of yield point and speed of testing.

On the recommendation of the subcommittee, a change is to be made in the Tentative Method of Bend Testing for Ductility of Metals (E 16 - 38 T) to indicate that this is intended to apply to tests for welds only. Members of the subcommittee have reviewed recommendations being made by Subcommittee IX to Committee E-1 to provide for more satisfactory test specimens for piping material as covered in the Standard Methods of Tension Testing of Metallic Materials (E 8).

Discussion of methods of limiting the rate of pulling brought out that for hydraulic testing machines it would be more convenient to use rate of load rather than rate of crosshead travel. Subsequent developments led to the appointment of a special committee including representatives of testing machine manufacturers who have been carrying out tests in an attempt to correlate rate of loading in hydraulic machines with rate of crosshead travel in screw machines, the purpose being eventually to set limits which would give concordant yield point values with both types of machines.

At both the January and March meetings, there was extended discussion not only at Subcommittee XIII's meeting, but at those of other subcommittees, on limiting speeds of testing which might be incorporated in the steel specifications. The committee had suggested the following limiting speeds:

> *For specimens with 8-in. gage lengths:*
>
> The free-running crosshead speed to be not less than $\frac{1}{16}$ in., nor more than $\frac{1}{2}$ in. per min. for determination of the yield point and not less than $\frac{1}{4}$ in. nor more than 2 in. per min. from yield point to the ultimate strength.
>
> *For specimens with 2-in. gage lengths:*
>
> The speed to be not more than $\frac{1}{8}$ in. per min. for determination of the yield point and not more than $\frac{1}{4}$ in. per min. from the yield point to the ultimate strength.

Subsequent discussion in numerous subcommittees crystallized criticism on the proposed speeds, particularly from the yield point to the ultimate strength, it being the feeling that in general the proposed speeds for determination of the yield point were satisfactory and in line with general practice, but that results had shown that a higher speed for determining ultimate strength than that recommended would not seriously affect the validity of values obtained.

Various specification-writing subcommittees are giving further thought to this and additional data are expected to be submitted to Subcommittee XIII.

Subcommittee XXI on Steel for Welding (N. L. Mochel, chairman).—Discussion of the scope of work of Subcommittee XXI has led to the conclusion that it no longer need be considered as an advisory group to the other subcommittees since in practically all cases the specification writing committees have qualified members conversant with welding requirements. The committee, however, is retaining its jurisdiction over the Filler Metal Specifications (A 205 – 37 T) and it may be necessary for the committee to supervise or to actually develop specifications for certain other materials suitable for welding as the occasion arises. The need for standard requirements for low-alloy steels suitable for fusion welding and used for various purposes has become evident. Consequently, the committee is retaining its complete personnel in readiness to handle promptly such subjects as are necessary.

Subcommittee XXII on Valves, Fittings, Piping and Flanges for High-Temperature Service (A. E. White, chairman).—Constant surveillance is necessary by this subcommittee to keep requirements in its various specifications for materials for high-temperature service in line with the latest manufacturing practices and with demands of consuming interests. A large number of grades of material offering satisfactory use in many services makes the work somewhat involved as well. During the year, the eleven specifications issued through the work of Subcommittee XXII have been reviewed and a number of changes are proposed for immediate adoption as detailed in the Appendix and revisions published as tentative in previous years are recommended for adoption.

Interest in welding fittings has grown to such an extent that a permanent new section of the committee under the chairmanship of J. J. Kanter has been appointed on this subject and is actively at work.

After a particularly intensive period of work, the Section on Castings, also headed by Mr. Kanter, has developed proposed Tentative Specifications for Carbon-Steel Castings Suitable for Fusion Welding for Service at Temperatures up to 850 F.[16] and proposed Tentative Specifications for Alloy-Steel Castings Suitable for Fusion Welding for Service at Temperatures from 750 to 1100 F.[16] which are being recommended for publication as tentative. There has been a very persistent demand for standardized requirements which should be met by the new specifications. At the same time two new grades of alloy steels of the 2 to 3 per cent chromium type as detailed in the Appendix are recommended for adoption in the Specifications for Alloy-Steel Castings for Valves, Flanges and Fittings for Service at Temperatures from 750 to 1100 F. (A 157 – 36).

General.—Action is being taken simultaneously with Committee A-2 on Wrought Iron, jointly responsible for the Standard Specifications for Iron and Steel Chain (A 56 – 30), to recommend the adoption as standard of the existing tentative revisions.

This report has been submitted to letter ballot of the committee which consists of 226 members; 156 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

N. L. MOCHEL,
Chairman.

H. P. BIGLER,
Secretary.

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[16] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

EDITORIAL NOTE

Subsequent to the annual meeting Committee A-1 presented the recommendations listed below to the Society on August 24, 1939, through Committee E-10 on Standards all of which were accepted. The new specifications were assigned the A.S.T.M. serial designations indicated. These new and revised tentative specifications and tentative revisions of standards are published in the 1939 Book of A.S.T.M. Standards, Part I.

New Tentative Specifications for:

Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 – 39 T),

Electric-Resistance-Welded Steel Boiler and Superheater Tubes for High-Pressure Service (A 226 – 39 T),

Hard-Drawn Steel Spring Wire (A 227 – 39 T),

Steel Music Spring Wire (A 228 – 39 T),

Oil-Tempered Steel Spring Wire (A 229 – 39 T),

Carbon-Steel Valve Spring Quality Wire (A 230 – 39 T),

Chromium-Vanadium Steel Spring Wire (A 231 – 39 T), and

Chromium-Vanadium Steel Valve Spring Quality Wire (A 232 – 39 T).

Proposed Revision of Tentative Specifications for:

Alloy-Steel Bolting Materials for High-Temperature Service from 750 to 1100 F. Metal Temperatures (A 193 – 37 T),

Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A 206 – 38 T), and

Alloy-Steel Castings Suitable for Fusion Welding for Service at Temperatures from 750 to 1100 F. (A 217 – 39 T).

Proposed Tentative Revision of Standard Specifications for:

Carbon-Steel and Alloy-Steel Forgings (A 18 – 30), in form of Tentative Specifications for Carbon-Steel Forgings (A 18 – 39 T), and

Electric-Resistance-Welded Steel and Open-Hearth Iron Boiler Tubes (A 178 – 37).

Withdrawal of Standard:

Specifications for Marine Boiler Steel Plates (A 114 – 33).

APPENDIX

PROPOSED REVISIONS IN STANDARDS FOR STEEL

In this Appendix are given proposed revisions in specifications covering steel and steel products as referred to earlier in this report. In connection with each title is given the reference to the publication in which the specifications appear in their present form.

Revisions in Permissible Variations

Previously in this report[1] there is discussed the general practice to be followed in bringing tables of permissible variations in many of the steel specifications in line with latest practice. It is desirable that the present tables be revised in accordance with the requirements which are given in the accompanying Tables I to VIII. There also appears a list of the A.S.T.M. specifications in which the respective tables or portions thereof will appear.

TABLE I.—PERMISSIBLE OVERWEIGHTS OF PLATES ORDERED TO THICKNESS.

Specified Thickness, in.	Permissible Excess in Average Weight of Lots for Widths Given, in., Expressed in Percentage of Nominal Weights										
	48 or under	Over 48 to 60, excl.	60 to 72, excl.	72 to 84, excl.	84 to 96, excl.	96 to 108, excl.	108 to 120, excl.	120 to 132, excl.	132 to 144, excl.	144 to 168, excl.	168 or over
3/16 to ¼, excl.	...	8	9	10	12	14	...	...	...	...	...
¼ to 5/16, excl.	6	7	8	9	10	12	14	16	19	...	...
5/16 to ⅜, excl.	5	6	7	8	9	10	12	14	17	18	...
⅜ to 7/16, excl.	4.5	5	6	7	8	9	10	12	15	16	18
7/16 to ½, excl.	4	4.5	5	6	7	8	9	10	13	14	16
½ to ⅝, excl.	3.5	4	4.5	5	6	7	8	9	11	12	14
⅝ to ¾, excl.	3	3.5	4	4.5	5	6	7	8	9	10	12
¾ to 1, excl.	2.5	3	3.5	4	4.5	5	6	7	8	9	11
1 to 2, incl.	2.5	2.5	3	3.5	4	4.5	5	6	7	8	9

NOTE.—Permissible variations in weight for individual plates shall be one and one-third times the amounts prescribed in this table.

TABLE II.—PERMISSIBLE VARIATIONS OF PLATES ORDERED TO WEIGHT.

Specified Weight, lb. per sq.ft.	Permissible Variations in Average Weight of Lots for Widths Given, in., Expressed in Percentage of Ordered Weights (Weight per Square Foot)																					
	48 or under		Over 48 to 60, excl.		60 to 72, excl.		72 to 84, excl.		84 to 96, excl.		96 to 108, excl.		108 to 120, excl.		120 to 132, excl.		132 to 144, excl.		144 to 168, excl.		168 or over	
	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under
7.65 to 10, excl.	...	...	4.5	3	5	3	5.5	3	6	3	...	...	...	...	...	...	...	...	...	...	...	
10 to 12.5, excl.	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3	9	3	...	...	...	
12.5 to 15, excl.	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3	...	...	...	
15 to 17.5, excl.	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3	9	3	10	3
17.5 to 20, excl.	2.5	2	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	8	3	9	3
20 to 25, excl.	2	2	2.5	2	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	7	3	8	3
25 to 30, excl.	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3	4.5	3	5	3	6.5	3	7	3
30 to 40, excl.	2	2	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3	4.5	3	6	3	6.5	3
40 to 81.6, incl.	2	2	2	2	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3	6	3	6.5	3

NOTE.—Permissible variations in weight for individual plates shall be one and one-third times the amounts prescribed in this table.

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[1] See p. 68.

TABLE III.—PERMISSIBLE VARIATIONS OVER ORDERED THICKNESS OF PLATES OVER 2 IN. IN THICKNESS.

Specified Thickness, in.	Variations over Specified Thickness for Widths Given					
	Up to 36, excl.	36 to 60, excl.	60 to 84, excl.	84 to 120, excl.	120 to 132, excl.	132 or over
Over 2 to 3, excl.	1/16	3/32	7/64	1/8	1/8	9/64
3 to 4, excl.	5/64	3/32	7/64	1/8	1/8	9/64
4 to 6, excl.	3/32	1/8	9/64	9/64	5/32	11/64
6 to 8, excl.	7/64	1/8	5/32	5/32	11/64	.....
8 to 10, excl.	.....	11/64	3/16	3/16	.....	.....
10 to 12, excl.	.....	3/16	15/64	15/64	.....	.....
12 to 15, incl.	.....	7/32	1/4	.....	.....	.....

TABLE IV.—PERMISSIBLE VARIATIONS IN THE SIZE OF HOT-ROLLED ROUNDS AND SQUARES.

Specified Size, in.	Variations from Size, in.		Out-of-Round or Square, in.
	Over	Under	
5/16 and under	0.005	0.005	0.008
Over 5/16 to 7/16, incl.	0.006	0.006	0.009
Over 7/16 to 5/8, incl.	0.007	0.007	0.010
Over 5/8 to 7/8, incl.	0.008	0.008	0.012
Over 7/8 to 1, incl.	0.009	0.009	0.013
Over 1 to 1 1/8, incl.	0.010	0.010	0.015
Over 1 1/8 to 1 1/4, incl.	0.011	0.011	0.016
Over 1 1/4 to 1 3/8, incl.	0.012	0.012	0.018
Over 1 3/8 to 1 1/2, incl.	0.014	0.014	0.021
Over 1 1/2 to 2, incl.	1/64	1/64	0.023
Over 2 to 2 1/2, incl.	1/32	0	0.023
Over 2 1/2 to 3 1/2, incl.	3/64	0	0.035
Over 3 1/2 to 4 1/2, incl.	1/16	0	0.046
Over 4 1/2 to 5 1/2, incl.	5/64	0	0.058
Over 5 1/2 to 8, incl.	3/32	0	0.070

NOTE.—Out-of-round is the difference between the maximum and minimum diameters of the bar, measured at the same cross-section. Out-of-square is the difference in the two dimensions at the same cross-section of a square bar.

TABLE V.—PERMISSIBLE VARIATIONS IN SIZE OF HEXAGONS.

Specified Size Between Opposite Sides, in.	Variations from Size, in.		Difference 3 Measurements, in.
	Over	Under	
1/2 and under	0.007	0.007	0.011
Over 1/2 to 1, incl.	0.010	0.010	0.015
Over 1 to 1 1/2, incl.	0.021	0.013	0.025
Over 1 1/2 to 2, incl.	1/32	1/64	1/32
Over 2 to 2 1/2, incl.	3/64	1/64	3/64
Over 2 1/2 to 3 1/2, incl.	1/16	1/64	1/16

TABLE VI.—PERMISSIBLE VARIATIONS IN WEIGHT, BAR-SIZE ANGLES, TEES, ZEES, AND CHANNELS.

Specified Size, in.	Variations from Weight, Over or Under, for Thicknesses Given	
	To 5/16, incl	Over 5/16
All dimensions to 1 1/2, incl.	7 per cent	5 per cent
Any dimension over 1 1/2	6 per cent	4 per cent

TABLE VII.—PERMISSIBLE VARIATIONS IN DIMENSIONS OF FLATS.

Specified Width, in.	Variations from Thickness, Over or Under, for Thicknesses Given, in.			Variations from Width, in.	
	1/4 to 1/2, incl.	Over 1/2 to 1, incl.	Over 1 to 2, incl.	Over	Under
1 and under	0.008	0.010	......	1/64	1/64
Over 1 to 2, incl.	0.012	0.015	1/32	1/32	1/32
Over 2 to 4, incl.	0.015	0.020	1/32	1/16	1/32
Over 4 to 6, incl.	0.015	0.020	1/32	3/32	1/16

NOTE.—The standard classification of flat hot-rolled steel products defines flat bars as not over 6 in. in width and not under 1/4 in. in thickness.

TABLE VIII.—PERMISSIBLE VARIATIONS IN DIMENSIONS OF ROUND-EDGE FLAT SPRING STEEL.

Specified Widths Over-all, in.	Variations from Thickness, Over or Under, for Thicknesses Given, in.			Variations from Width, Over or Under, in.
	3/8 and under	Over 3/8 to 5/8, incl.	Over 5/8 to 1, incl.	
2 and under	0.008	0.012	....	1/64
Over 2 to 4, incl.	0.010	0.012	....	1/32
Over 4 to 6, incl.	0.010	0.012	0.015	3/64
Over 6 to 8, incl.	0.012	0.015	0.020	3/32

LIST OF SPECIFICATIONS CONTAINING TABLES OF PERMISSIBLE VARIATIONS

	TABLES
Specifications for Structural Nickel Steel (A 8 – 38)	I, II
Specifications for Structural Rivet Steel (A 141 – 38)	IV
Specifications for Steel for Bridges (A 7 – 36)	I, II, III
Specifications for Steel for Buildings (A 9 – 36)	I, II, III
Specifications for Mild Steel Plates (A 10 – 34)	I, II, III
Specifications for Structural Steel for Locomotives and Cars (A 113 – 33)	I, II, IV, V, VI, VII
Specifications for Structural Silicon Steel (A 94 – 36)	I, II
Specifications for Steel Plates of Structural Quality for Forge Welding (A 78 – 33)	I, II
Tent. Specifications for High-Strength Structural Rivet Steel (A 195 – 36 T)	IV
Tent. Specifications for Low-Carbon-Nickel Steel Plates for Boilers and Other Pressure Vessels (A 203 – 37 T)	I
Specifications for Marine Boiler Steel Plates (A 114 – 33)	I
Specifications for Carbon-Steel Bars for Railway Springs (A 14 – 27)	IV, VIII
Specifications for Silico-Manganese-Steel Bars for Railway Springs (A 59 – 27)	IV, VIII
Specifications for Chromium-Vanadium-Steel Bars for Railway Springs (A 60 – 27)	IV, VIII
Specifications for Carbon-Steel Bars for Railway Springs with Special Silicon Requirements (A 68 – 36)	IV, VIII
Specifications for Boiler and Firebox Steel for Locomotives (A 30 – 38)	I
Specifications for High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates 2 in. and Under in Thickness (A 149 – 38)	I
Specifications for High Tensile Strength Carbon-Silicon-Steel Plates for Boilers and Other Pressure Vessels (Plates over 2 to 4½ in., Inclusive, in Thickness (A 150 – 38).	III
Specifications for Carbon-Silicon-Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 – 38)	I, III
Specifications for Chrome-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 – 38)	I
Specifications for Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 – 38)	I, III
Specifications for Structural Steel for Ships (A 131 – 36)	I, II, IV, V, VI, VII
Specifications for Boiler Rivet Steel and Rivets (A 31 – 36)	IV
Specifications for Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (A 70 – 36)	I, III
Specifications for Open-Hearth Iron Plates of Flange Quality (A 129 – 33)	I
Specifications for Steel Plates of Flange and Firebox Qualities for Forge Welding (A 89 – 33)	I
Specifications for Commercial Quality Hot-Rolled Bar Steels (A 107 – 36)	IV, V, VII
Specifications for Electric-Fusion-Welded Steel Pipe for High-Temperature and High-Pressure Service (A 155 – 36)	I

Revisions of Tentative Standards

Tentative Specifications for Heat-Treated Carbon- and Alloy-Steel Track Bolts (A 183 – 36 T):[2]

Section 3 (*b*).—Change from its present form: namely,

> (*b*) The steel for the nuts shall conform to the commercial quality of hot-rolled nut bar steel, and shall have a carbon range of from 0.15 to 0.25 per cent for open-hearth steel, 0.08 to 0.16 per cent for bessemer steel.

to read as follows:

> (*b*) The steel for the nuts shall conform to the resulfurized nut stock grade Nos. 26 and 27 of the Standard Specifications for Commercial Quality Hot-Rolled Bar Steels (A.S.T.M. Designation: A 107) of the American Society for Testing Materials.

Section 9.—Change from its present form: namely,

> 9. The threads of the nut shall not "strip" when the bolt, with nut fully mounted, is tested in tension to its yield point, the load being applied to the head of the bolt and the bearing side of the nut.

to read as follows:

> 9. The threads of the nut shall not "strip" when the bolt, with nut fully mounted, is tested in tension to the minimum yield point specified in Section 6 (*a*) based upon the circular area calculated from the nominal root diameter (basic minor diameter) of the bolt.

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[2] *Proceedings*, Vol. 36, Part I (1936); also 1938 Book of A.S.T.M. Tentative Standards.

Tentative Specifications for High-Strength Structural Rivet Steel (A 195 – 36 T)[2]

Section 7 (a).—In the tabulation of tensile properties change the tensile strength range from "70,000 to 85,000 psi." to read "68,000 to 82,000 psi."

Tentative Specifications for Normalized Quenched-and-Tempered Alloy-Steel Forgings (A 63 – 38 T):[3]

Section 12.—Delete this section on proof tests, renumbering the following sections accordingly.

Appendix.—Delete this appendix, which gives supplementary information relative to proof tests.

Tentative Specifications for Seamless Steel Boiler Tubes for High-Pressure Service (A 192 – 38 T):[3]

Section 17.—As an editorial revision, change from its present form: namely,

> 17. The name or brand of the manufacturer, the words Seamless Steel, A.S.T.M. Specification A 192 – 38 T, the hydrostatic test pressure in pounds per square inch, and whether hot finished or cold drawn, shall be legibly stenciled on each tube.

to read as follows:

> 17. (*a*) The name or brand of the manufacturer, the words Seamless Steel, A.S.T.M. Specification A 192 – 39 T, together with the hydrostatic test pressure in pounds per square inch, and whether hot finished or cold drawn, shall be legibly stenciled on each tube 1¼ in. in outside diameter and over, provided the length is not under 3 ft.
>
> (*b*) On tubes less than 1¼ in. in diameter and on all tubes under 3 ft. in length, the information prescribed in Paragraph (*a*) shall be marked on a tag securely attached to the bundle or box in which the tubes are shipped.

Tentative Specifications for Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A 206 – 38 T):[3]

Section 3.—Add a new paragraph designated as Paragraph (*d*) to read as follows:

> (*d*) The steel melting practice shall be such as will produce a ferritic grain size in the finished pipe corresponding to an A.S.T.M. grain size of 3 to 6 under the following conditions: (*1*) in hot-finished pipe in the as-finished condition; (*2*) in bends and other fabricated parts which are heated and possibly water-quenched, if subsequently annealed at 1700 F. and slow-cooled in the furnace at a rate not to exceed 50 F. per hour until below 1000 F.

Section 5.—Change from its present form: namely,

> 5. The finished pipe shall be furnished in the normalized and drawn condition unless otherwise specified in the purchase order.

to read as follows:

> 5. The hot-rolled pipe after finishing shall be given a stress-relief anneal by heating in a furnace to approximately 1200 F. followed by furnace cooling at a rate not to exceed 50 F. per hour until below 1000 F.

Supplementary Requirements.—Add a Paragraph (*b*) to Section S5 to read as follows, relettering the present section as Paragraph (*a*):

> (*b*) The ferritic grain size of the steel in each piece of pipe, as shown in a photomicrograph, shall not be coarser than No. 3, nor finer than No. 6 grain size, in accordance with the Tentative Grain Size Chart for Classification of Steels (E 19 – 38 T) of the American Society for Testing Materials.

Appendix.—In the table, add in the appropriate places the following four pipe sizes, with their schedule numbers and thicknesses:

Nominal Pipe Size, in.	Service up to 1400 psi. at 950 F.		Service up to 900 psi. at 900 F.	
	Schedule No.	Thickness, in.	Schedule No.	Thickness, in.
½	160	0.187	160	0.187
1	160	0.250	160	0.250
2	160	0.343	160	0.343
3	160	0.437	160	0.437

Tentative Specifications for One-Wear and Two-Wear Wrought Steel Wheels (A 186 – 36 T):[2]

Section 9 (p).—Change from its present form: namely,

> (*p*) *Depression of Hub.*—The depression of the hub below the front face of the rim shall not

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[3] *Proceedings*, Vol. 38, Part I (1938); also 1938 Book of A.S.T.M. Tentative Standards.

be less, but may be ¼ in. more, than that specified, based on specified rim width.

to read as follows:

(*p*) *Depression of Hub.*—The distance from the vertical reference line to the front face of the hub shall not be more but may be ¼ in. less than that specified.

Tentative Revision of Standard

Standard Specifications for Boiler and Firebox Steel for Locomotives (A 30 - 38):[4]

Section 3.—In the table of chemical composition add a requirement for incidental copper content for firebox steel of 0.25 max. per cent.

Revisions of Standards, Immediate Adoption

Standard Specifications for Open-Hearth Carbon-Steel Rails (A 1 - 36):[5]

Section 10.—Change Paragraph (*a*) to read as follows by the addition of the italicized words and the omission of those in brackets:

(*a*) *Elongation.*—One of the three test specimens shall be given a sufficient number of blows to determine, for information only, the exhausted ductility, reported inch by inch over the entire 6 in. [gage length] *gaged.* No ductility readings shall be taken between blows.

Change Paragraph (*b*) from its present form: namely,

(*b*) *Interior Condition.*—The remaining two specimens shall be nicked and broken. The fracture of each specimen shall be examined and if the fracture on any test specimen exhibits seams, laminations, cavities, interposed foreign matter, or a distinctly bright or fine-grained structure, all top rails represented shall be classified as "X-Rayls."

to read as follows:

(*b*) *Interior Condition.*—A test piece representing the top end of the top rail of each ingot of each heat rolled, which has passed the drop test requirements of Section 9, shall be nicked and broken. If the fracture on any test specimen exhibits seams, laminations, cavities, interposed foreign matter, or a distinctly bright or fine-grained structure, the top rail represented shall be classed as an "X-Rayl."

Standard Specifications for Carbon-Steel Bars for Railway Springs (A 14 - 27):[4]

Title.—Change the title of these specifications by the omission of the word "Railway."

Section 1.—Change the first sentence of this section to read as follows by the addition of the italicized word and the omission of the word in brackets:

These specifications cover two grades of *hot-rolled* carbon-steel bars to be used for the manufacture of [railway] springs, determined by the carbon ranges specified in Section 3.

Section 3.—In the table of chemical composition change the requirement for manganese for both grades A and B from "0.50 max. per cent" to read "0.25 to 0.50 per cent."

Standard Specifications for Silico-Manganese-Steel Bars for Railway Springs (A 59 - 27):[5]

Title.—Change the title of these specifications by the omission of the word "Railway."

Section 1.—Change to read as follows by the addition of the italicized word and the omission of the word in brackets:

1. These specifications cover *hot-rolled* silico-manganese-steel bars to be used for the manufacture of [railway] springs.

Standard Specifications for Chromium-Vanadium-Steel Bars for Railway Springs (A 60 - 27):[5]

Title.—Change the title of these specifications by the omission of the word "Railway."

Section 1.—Change to read as follows by the addition of the italicized word and the omission of the word in brackets:

1. These specifications cover *hot-rolled* chromium-vanadium-steel bars to be used for the manufacture of [railway] springs.

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[4] 1938 Supplement to Book of A.S.T.M. Standards.
[5] 1936 Book of A.S.T.M. Standards, Part I.

Standard Specifications for Carbon-Steel Bars for Railway Springs with Special Silicon Requirements (A 68 – 36):[5]

Title.—Change the title of these specifications by the omission of the word "Railway."

Section 1.—Change to read as follows by the addition of the italicized words:

> 1. These specifications cover *hot-rolled* carbon-steel bars *with special silicon requirements* to be used for the manufacture of railway *and general purpose* springs.

Standard Specifications for Multiple-Wear Wrought Steel Wheels (A 57 – 36):[5]

Section 8 (p).—Change from its present form: namely,

> (*p*) *Depression of Hub.*—For car and tender wheels and wheels of similar design, with journal-box bearing on front face of the hub, the depression of the hub below the front face of the rim shall not be less but may be $\frac{1}{8}$ in. more than that specified, based on specified rim width.

to read as follows:

> (*p*) *Depression of Hub.*—For car and tender wheels and wheels of similar design with journal-box located at the front face of the hub, the distance from the vertical reference line to the front face of the hub shall not be more but may be $\frac{1}{8}$ in. less than that specified.

Standard Specifications for Boiler Rivet Steel and Rivets (A 31 – 36):[5, 6]

Section 2.—In the table of chemical composition add the following requirements for a new grade of high-tensile strength boiler rivet steel:

Carbon, max., per cent	0.27
Manganese, per cent	0.40 to 0.80
Phosphorus, max., per cent	0.04
Sulfur, max., per cent	0.05
Silicon, max., per cent	0.30

Section 5.—In the table of tensile properties add the following requirements for a new grade of high-tensile strength boiler rivet steel:

Tensile strength, psi	58 000 to 68 000
Yield point, min., psi	0.5 tens. str.
but in no case less than	32 000
Elongation in 8 in., min., per cent	$\frac{1\,500\,000}{\text{tens. str.}}$
but in no case less than	23

Standard Specifications for Open-Hearth Iron Plates of Flange Quality (A 129 – 33):[5]

Section 13.—Delete Paragraphs (*b*), (*c*), and (*d*) covering match-marking from this section.

Standard Specifications for Steel Plates of Flange and Firebox Qualities for Forge Welding (A 89 – 33):[5]

Section 14.—Delete Paragraphs (*b*), (*c*), and (*d*) covering match-marking from this section.

Standard Specifications for Carbon-Silicon-Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 – 38):[4]

Section 9.—Change the table giving diameter of pin about which the specimen is bent to provide that for material "over 4 to 6 in., incl." the pin diameter for Grade A shall be "$2\frac{1}{2}t$" instead of "$2t$," and for Grade B, "$3t$" instead of "$2\frac{1}{2}t$," where t is the thickness of specimen.

Standard Specifications for Alloy-Steel Bolting Material for High-Temperature Service (A 96 – 33):[5]

Section 13.—Add a new Paragraph (*a*) to read as follows, relettering the subsequent paragraphs accordingly:

> (*a*) For bars, one tension test shall be made from each tempering charge. If more than one heat treatment charge is represented in a tempering charge, one tension test shall be made

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See Footnote 12, p. 71.

from each heat treatment charge. If more than one melt is represented in a heat treatment charge, one tension test shall be made from each melt.

Change the relettered Paragraphs (*b*), (*c*) and (*e*) to read as follows by the addition of the italicized material and the omission of that in brackets (no change in Paragraph (*d*)):

> (*b*) Except as specified in Paragraph (*c*) one tension test shall be made for each lot of *300* [100] pieces or fraction thereof of *bolts, screws, and studs for sizes up to and including 2½ in. in diameter; or for each lot of 100 pieces or fraction thereof for sizes over 2½ in.* [bolting material from each tempering charge. If more than one quenching charge is represented in a tempering charge, one tension test shall be made from each lot of 100 pieces or fraction thereof from each quenching charge. If more than one melt is represented in a quenching charge, one tension test shall be made from each lot of 100 pieces or fraction thereof from each melt.]
>
> (*c*) Unless required on the order, tension tests shall not be made on an order of less *quantity than specified in Paragraph* (*b*) [than 100 bolts, screws or studs]; in which case acceptance shall be based upon the provisions in Section 2 or 3.
>
> (*e*) If the percentage of elongation of any *tension* test specimen is less than that specified in Section 10 (*a*) and any part of the fracture is *more than 3/4 in. from the center* [outside of the middle three-fourths] of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

Standard Specifications for Alloy-Steel Castings for Valves, Flanges, and Fittings for Service at Temperatures from 750 to 1100 F. (A 157 – 36):[5]

Section 1 (*b*).—Change the first sentence to read as follows by the addition of the italicized words and the omission of the words in brackets:

> [Eight] *Ten* grades of materials are included, [six] *eight* ferritic steels and two austenitic steels designated C 1, C 2, etc., which are classified in accordance with their chemical and physical properties as specified in Sections 5 and 8.

Section 2.—Change the first sentence to read as follows by the addition of the italicized symbols:

> Steels C 1, C 2, *C 3a*, *C 3b*, C 4, C 5, and C 11 shall be made by the open-hearth, crucible, or electric-furnace process.

Section 3 (*b*).—Change to read as follows by the addition of the italicized symbols:

> (*b*) The ferritic steels C 1, C 2, *C 3a, C 3b,* C 4, C 5, C 6, and C 11 may be fully annealed, or fully annealed and drawn, or normalized and drawn, or annealed and normalized and drawn, or normalized and annealed.

Section 5.—To the table of chemical composition add the following requirements for the new grades designated as C 3a and C 3b:

	Grade C 3a	Grade C 3b
Carbon, max., per per cent	0.35	0.35
Manganese, max, per cent	1.00	1.00
Phosphorus, max., per cent	0.05	0.05
Sulfur, max., per cent	0.06	0.06
Silicon, per cent	0.50 max.	0.75 to 1.25
Chromium, per cent	1.50 to 2.25	1.50 to 2.25
Molybdenum, per cent	0.45 to 0.65	0.45 to 0.65

Section 8 (*a*).—In the tabulation of tensile properties, add the following requirements for the new grades designated as C 3a and C 3b:

	Grades C 3a and C 3b
Tensile strength, min., psi	100 000
Yield point, min., psi	65 000
Elongation in 2 in., min., per cent	18
Reduction of area, min., per cent	30

Standard Specifications for Forged or Rolled Steel Pipe Flanges for High-Temperature Service (A 105 – 36):[5]

Section 6 (*a*).—In the table of chemical requirements change the manganese content for classes I and II from "0.40 to 0.80 per cent" to read "0.90 max. per cent."

Standard Specifications for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for Service at Temperatures from 750 to 1100 F. (A 182 – 36):[5]

Section 11 (*a*).—In the tabulation of tensile properties change the requirements for Grade F 8 to read as follows by the addition of the italicized figures and the omission of those in brackets:

Tensile strength, min., psi.	[80 000] *75 000*
Yield point, min., psi.	[40 000] *30 000*
Elongation in 2 in., min., per cent	[35] *45*
Reduction of area, min., per cent	50

Standard Specifications for Lap-Welded and Seamless Steel Pipe for High-Temperature Service (A 106 – 36):[5]

Section 2 (*a*).—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

(*a*) The steel for lap-welded pipe shall be of good weldable quality made by the open-hearth process. [The steel for] *All* seamless pipe [may] *shall* be made *of killed steel* by either or both of the following processes: open-hearth or electric-furnace.

REPORT OF SECTIONAL COMMITTEE ON STANDARDIZATION OF DIMENSIONS AND MATERIALS OF WROUGHT-IRON AND WROUGHT-STEEL PIPE AND TUBING

A.S.A. Project: B36

No meeting of the Sectional Committee on Standardization of Dimensions and Materials of Wrought-Iron and Wrought-Steel Pipe and Tubing was held during the past year. However, revision of the American Tentative Standard for Wrought-Iron and Wrought-Steel Pipe (A.S.A. B36.10 – 1935) which was initiated in 1937 was consummated in 1938 by correspondence. The revised standard was transmitted on January 27, 1939, to the American Standards Association for approval as American standard.

The changes and additions to the proposed American standard consist of the following:

1. The advancement of the American tentative standard to the status of American standard;

2. The addition to the list of specifications included in Table 1 (Part 1) of the A.S.T.M. Standard Specifications for Electric-Fusion-Welded Steel Pipe for High-Temperature and High-Pressure Service (A.S.T.M. A 155 – 36);

3. A reaffirmation of the vote to include in Table 1 (Part 1) the A.S.T.M. Standard Specifications for Welded Wrought-Iron Pipe (A.S.T.M. A 72 – 38);

4. The inclusion as information as additions to Table 1 (Part 2) of the listing of the A.S.T.M. Specifications for Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A.S.T.M. A 206 - 38 T), and for Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A.S.T.M. A 158 – 38 T). Since these two specifications together with A.P.I. Specifications 5 – L are not American standards, a change was made in the heading of Table 1 (Part 2) to denote this fact;

5. Revision of the second note under Tables 2 and 4 to read:

> The decimal thicknesses listed for the respective pipe sizes represent their nominal or average wall dimensions. For tolerances on wall thicknesses, see appropriate material specification.

6. Addition of a parenthetical clause "(see Introductory Notes, Section 8)" to the last footnote in Tables 2, 3, 4, and 5;

7. Addition of a footnote to Tables 2 and 4, respectively, to make provision for the temporary use of two pipe thicknesses of the old "standard weight" and "extra strong" series, as follows:

> *Table 2:* Owing to a necessary departure from the old "standard-weight" and "extra-strong" thicknesses in these two sizes, the new thicknesses are not as yet stocked by all manufacturers and jobbers. Hence, where agreeable to the purchaser and suitable for the service conditions, the old "standard-weight" 0.375-in. wall pipe corresponding to a 1000 P/S value of 37.7 is still available and can be substituted for the 0.406-in. wall pipe, and the old "extra-strong" 0.500-in. wall pipe corresponding to a 1000 P/S value of 55 can be substituted for the 0.562-in. wall pipe.

Table 4: Owing to a necessary departure from the old "standard-weight" and "extra-strong" thicknesses in these two sizes, the new thicknesses are not as yet stocked by all manufacturers and jobbers. Hence, where agreeable to the purchaser and suitable for the service conditions, the old "standard-weight" 0.382-in. wall pipe corresponding to a 1000 *P/S* value of 38.7 is still available and can be substituted for the 0.414-in. wall pipe, and the old "extra-strong" 0.510-in. wall pipe corresponding to a 1000 *P/S* value of 56.3 can be substituted for the 0.574-in. wall pipe.

Items 1, 2, 4, and 5 were submitted to letter ballot of the committee which consists of 41 members; 41 members returned their ballots, all of whom voted affirmatively. The remaining items were considered editorial changes and were not referred to letter ballot vote. The revised draft has been approved by the A.S.A. with the designation B36.10-1939.

Two A.S.T.M. specifications for piping material were submitted to the members of the sectional committee for approval and presentation to the American Standards Association. One of these was the Standard Specifications for Welded Wrought-Iron Pipe (A 72 – 38) on which the vote in the committee resulted as follows: Of a membership of 41, 39 members returned their ballots, of whom 35 voted affirmatively, 0 negatively, and 4 members marked their ballots "not voting." An earlier edition of these specifications (A 72 – 33) was approved by the A.S.A. and was listed in Table 1 (Part 1) of American Tentative Standard B36.10 – 1935. The present revision was accordingly presented to the sectional committee and approved for transmission to the A.S.A., and approved by the A.S.A. with the designation B36.2-1939.

The other A.S.T.M. specifications presented were the Standard Specifications for Electric-Fusion-Welded Steel Pipe for High-Temperature and High-Pressure Service (A 155 – 36) on which the vote was as follows: Of a membership of 41, 39 members returned their ballots, of whom 34 voted affirmatively, 1 negatively, and 4 members marked their ballots "not voting." This specification was approved by the A.S.A. as an American standard with the designation B36.11-1939.

The committee recommended in particular that as soon as the Tentative Specifications for Carbon-Molybdenum Alloy-Steel Pipe (A.S.T.M. A 206 – 38 T) were adopted by the A.S.T.M., they should be submitted for approval as American standard.

With advancement of the B36 Pipe Standard from the tentative status to that of an American standard, the committee plans to advocate more widespread adoption of the standard by industry through publication in trade magazines of several articles explaining its purpose and advantages, particularly to jobbers and the heating and plumbing trades which are users of large quantities of pipe. The officers of the committee prepared an article entitled "Use the New American Pipe Standard" which was published in a trade journal in October, 1938, following which 1000 reprint copies were distributed to industry. Further cooperation of the A.S.M.E., the A.S.T.M., the A.S.A., and other organizations, together with a concerted effort by their individual members, is solicited in acquainting the trade with the merits and desirability of employing the B36 Pipe Standard in ordering wrought-iron and wrought-steel pipe.

Respectfully submitted on behalf of the committee,

H. H. MORGAN,
Chairman.

SABIN CROCKER,
Secretary.

REPORT OF COMMITTEE A-2

ON

WROUGHT IRON

Committee A-2 on Wrought Iron has held one meeting since the 1938 annual meeting of the Society: on March 7, 1939, in Columbus, Ohio.

It is with regret that the committee records the death on July 30, 1938, of J. B. Young, Engineer of Tests of the Reading Co., who served as secretary of Committee A-2 from 1912 to 1924, and as chairman from 1936 to 1938.

James Aston has been elected chairman of Subcommittee VII on Nomenclature and Definitions, and E. B. Story as chairman of Subcommittee I on Tubes and Pipe. The resignation of O. W. Hovis, Engineer of Materials and Tests of the Tennessee Highway Department, has been recorded.

I. REVISION OF TENTATIVE STANDARD

The committee recommends the following revision, proposed by Subcommittee II, in the Tentative Specifications for Single and Double Refined Wrought Iron Bars (A 189 – 37 T):[1]

> *Section 5 (a).*—Due to the fact that in the heading of the second column of the table of tensile properties the present wording does not include $1\frac{5}{8}$-in. bars, it is recommended that the heading of this column be changed to read as follows by the omission of the word in brackets:
>
> Round, Square, and Hexagonal Bars [over] $1\frac{5}{8}$ in. and up to but not including $2\frac{1}{2}$ in. in Diameter or Thickness.
>
> In order to bring these specifications in line with the Tentative Specifications for Wrought-Iron Rivets and Rivet Rounds (A 152 – 37 T), the elongation requirements of which were arrived at after considerable research, it is recommended that footnote "a" to the table be changed to read as follows by the addition of the italicized words and the omission of those in brackets:
>
> [a] Bars [not exceeding $\frac{7}{8}$ in. in diameter or thickness] *from $\frac{1}{2}$ to $\frac{7}{8}$ in. in diameter* will be accepted if the elongation in 8 in. is not less than 25 per cent for Grade A [and] *or* 22 per cent for Grade B material. *Bars not exceeding $\frac{7}{16}$ in. in diameter will be accepted if the elongation in 8 in. is not less than 22 per cent for Grade A and for Grade B material.*
>
> Insert a footnote reference "c" after the tensile strength requirements in the third column of the table for both grades A and B iron, the footnote to read as follows:
>
> [c] When the cross-sectional area exceeds 12 sq. in., the allowable minimum tensile strength shall be 45,000 psi.

II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative specifications be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Specifications for:

Wrought-Iron Plates (A 42 – 37 T),[1] proposed by Subcommittee IV on Plates, Shapes, and Sheets (James Aston, chairman),

Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 – 38 T),[2] joint recommendation with Committee A-1 on Steel,[3]

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, pp. 649, 653, 659 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 219, 223, 229.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 531, 611 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 66, 234.

[3] These specifications will remain tentative until similar action is taken by Committee A-1 on Steel.—ED.

Wrought-Iron Rivets and Rivet Rounds (A 152 – 37 T),[1] proposed by Subcommittee II on Wrought Iron Bars (J. Porter Gillespie, chairman), and

Wrought-Iron Shapes and Bars (A 207 – 38 T),[2] proposed by Subcommittee IV.

III. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

The committee recommends that the tentative revisions[4] published in 1937 of the following specifications be approved for reference to letter ballot of the Society for adoption as standard, with a further revision in one of the specifications as indicated below:

Standard Specifications for:

Iron and Steel Chain (A 56 – 30), proposed by Subcommittee V on Chain Iron and Iron Chain (E. L. Johnson, chairman), joint recommendation with Committee A-1 on Steel,

Welded Wrought-Iron Pipe (A 72 – 38; A.S.A. B36.2-1939), proposed by Subcommittee I on Tubes and Pipe (E. B. Story, chairman),

Staybolt Wrought Iron, Solid (A 84 – 36), and Staybolt Wrought Iron, Hollow Rolled (A 86 – 36), proposed by Subcommittee II on Wrought Iron Bars (J. Porter Gillespie, chairman), except that the present rolling tolerances will be retained in these two specifications without change until such time as the Association of American Railroads changes the tolerances in its specifications for staybolts, inasmuch as the A.S.T.M. and A.A.R. specifications are now in agreement with respect to rolling tolerances,

Uncoated Wrought-Iron Sheets (A 162 – 36; A.S.A. G23-1937), proposed by Subcommittee IV (James Aston, chairman),

Zinc-Coated (Galvanized) Wrought-Iron Sheets (A 163 – 36; A.S.A. G8.8-1937), proposed by Subcommittee IV, and by Subcommittee XI on Galvanizing of Pipes and Sheets (James Aston, chairman), and

Wrought-Iron Rolled or Forged Blooms and Forgings (A 73 – 36), proposed by Subcommittee VI on Wrought-Iron Blooms and Forgings (Thomas Jameson, chairman) with the following further revision:

Section 2 (a).—Add a sentence at the end of this section to read as follows:

In the final piling, all bars shall be of the full length of the pile; the original muck bars shall be piled, rolled or forged, repiled, and rerolled or reforged.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 57 members; 43 members returned their ballots, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF TENTATIVE STANDARD			
Spec. for Single and Double Refined Wrought-Iron Bars (A 189 – 37 T)	43	0	0
II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for Wrought-Iron Plates (A 42 – 37 T)	34	0	9
Spec. for Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 – 38 T)[3]	34	1	8
Spec. for Wrought-Iron Rivets and Rivet Rounds (A 152 – 37 T)	39	1	3
Spec. for Rolled Wrought-Iron Shapes and Bars (A 207 – 38 T)	38	0	5
III. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Spec. for Iron and Steel Chain (A 56 – 30)	38	0	5
Spec. for Welded Wrought-Iron Pipe (A 72 – 38; A.S.A. B36.2-1939)	33	0	10
Spec. for Staybolt Wrought Iron, Solid (A 84 – 36)	37	1	5
Spec. for Staybolt Wrought Iron, Hollow Rolled (A 86 – 36)	36	0	7
Spec. for Uncoated Wrought-Iron Sheets (A 162 – 36; A.S.A. G23-1937)	31	0	12
Spec. for Zinc-Coated (Galvanized) Wrought-Iron Sheets (A 163 – 36; A.S.A. G8.8-1937)	30	0	13
Spec. for Wrought-Iron Rolled or Forged Blooms and Forgings (A 73 – 36)	34	0	9

This report has been submitted to letter ballot of the committee which consists of 57 members; 47 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

C. B. BRYANT,
Chairman.

W. C. MASTERS,
Secretary.

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1314 to 1317, incl. (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1680 to 1683, incl.

REPORT OF COMMITTEE A-3

ON

CAST IRON

Since the 1938 annual meeting of the Society, Committee A-3 on Cast Iron has held one meeting, in Columbus, Ohio, on March 9, 1939. The second meeting will be held in June during the annual meeting of the Society.

The present membership of the committee is 109, of which 30 are classified as producers, 44 as consumers, and 35 as general interest members.

Subcommittee IV on Car Wheels (F. K. Vial, chairman) is considering a change in wheel design but does not have definite recommendations to make at this time for revision of the Tentative Specifications for Chilled-Tread Cast-Iron Wheels (A 46 - 30 T).

Subcommittee VI on General Castings (J. W. Bolton, chairman) has proposed the withdrawal of the Standard Specifications for the Arbitration Test Bar and Tension Test Specimen for Cast Iron (A 124 - 29). This subcommittee has under consideration a revision of the Standard Specifications for Gray-Iron Castings (A 48 - 36) which will provide a requirement for breaking load in the transverse test for class No. 60 castings (60,000 psi. minimum tensile strength) using transverse test bar C, 2 in. in diameter when tested on 24-in. supports.

Subcommittee XIX on Chilled and White Iron Castings (Johannes Erler, chairman) is giving consideration to the type of test specimens to be used for this class of iron.

Subcommittee XX on Soil Pipe (Walker Reynolds, chairman) has in preparation revised specifications for cast-iron soil pipe and fittings which are intended to replace the present Standard Specifications for Cast-Iron Soil Pipe and Fittings (A 74 - 29). It is expected that the revised specifications, which are in general accordance with and complementary to the American Standard A40.1-1935, will be acted on by Committee A-3 at its meeting during this annual meeting and submitted to the Society for publication as tentative through Committee E-10 on Standards later in the year.[1]

WITHDRAWAL OF STANDARD

The committee recommends the withdrawal of the Standard Specifications for the Arbitration Test Bar and Tension Test Specimen for Cast Iron (A 124 - 29),[2] as proposed by Subcommittee VI. This recommendation has been submitted to letter ballot of the committee which consists of 109 members; 76 members returned their ballots, of whom 70 voted affirmatively, 1 negatively, and 5 members marked their ballots "not voting."

This report has been submitted to letter ballot of the committee which consists of 109 members; 78 members returned their ballots, of whom 74 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. H. ROTHER,
Chairman.

H. C. AUFDERHAAR,
Secretary.

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[1] See Editorial Note, p. 93.

[2] 1936 Book of A.S.T.M. Standards, Part I, p. 489.

EDITORIAL NOTE

Subsequent to the annual meeting Committee A-3 on Cast Iron presented to the Society through Committee E-10 on Standards the following recommendations:

Proposed Tentative Specifications for:

Cast Iron Pit-Cast Pipe for Water or Other Liquids, to replace immediately the Standard Specifications for Cast Iron Pipe and Special Castings (A 44 - 04), and

Cast Iron Soil Pipe and Fittings, to replace immediately the Standard Specifications for Cast Iron Soil Pipe and Fittings (A 74 - 29).

These recommendations were accepted by Committee E-10 on August 24, 1939, and the new tentative specifications appear in the 1939 Book of A.S.T.M. Standards, Part I.

REPORT OF COMMITTEE A-5

ON

CORROSION OF IRON AND STEEL

Committee A-5 on Corrosion of Iron and Steel has held two meetings during the past year: one on June 29, 1938, during the annual meeting of the Society in Atlantic City, N. J., and the other on March 8, 1939, at the spring group meetings of A.S.T.M. committees in Columbus, Ohio.

Since the last report, 4 new members have been elected, 3 members have resigned, and 4 members have died; the committee membership now totals 123, of whom 54 are classified as producers, 44 as consumers, and 25 as general interest members.

I. NEW TENTATIVE STANDARDS

The committee recommends that the following new specifications and methods be accepted for publication as tentative:

Tentative Specifications for Zinc-Coated Steel Wire Strand (Class B and Class C Coatings),[1] on the recommendation of Subcommittee VI on Specifications for Metallic-Coated Products (T. R. Galloway, chairman). These specifications cover strand with heavier coatings than those called for in the Standard Specifications for Zinc-Coated (Galvanized) Iron or Steel Wire Strand (Cable) (A 122 - 33). Three wire strand and a fifth strength classification called "utilities grade" have been included in the new specifications.

Tentative Methods of Test for Local Thickness of Electrodeposited Coatings on Steel,[2] on the recommendation of Subcommittee VII on Methods of Testing (R. W. Baker, chairman). These methods include a microscopic method for determining the thickness of zinc, cadmium, copper, and nickel coatings on steel, and a hydrochloric acid spot test method for determining the thickness of chromium coatings. They will supply a method for determining compliance with the coating thickness requirements of the Tentative Specifications for Electrodeposited Coatings of Zinc on Steel (A 164 - 35 T), Cadmium on Steel (A 165 - 35 T), and Nickel and Chromium on Steel (A 166 - 35 T) for which there has been no A.S.T.M. method available. The new methods represent a great amount of research work by the National Bureau of Standards and members of this committee.

II. REVISIONS OF TENTATIVE STANDARDS

The committee recommends that the three tentative specifications listed below be revised on the recommendation of Subcommittees VI and VII and continued as tentative. The revisions include new material on sampling methods and on the acceptance and rejection of material as a result of test, reference to the new Tentative Methods of Test for Local Thickness of Electrodeposited Coatings on Steel,[2] and in the case of the third specification, a change in the thickness requirement for chromium from average to minimum. In the three specifications the microscopic method is recommended for determining the thickness of zinc, cadmium, copper, and nickel coatings, and the hydrochloric acid spot test method is recommended for determining the thickness of chromium coatings. The specifications in their revised form are presented herewith:[1]

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[1] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

[2] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

Tentative Specifications for:

Electrodeposited Coatings of Zinc on Steel (A 164 – 35 T),[3]
Electrodeposited Coatings of Cadmium on Steel (A 165 – 35 T),[3] and
Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 – 35 T).[3]

III. REVISIONS OF STANDARDS

On the recommendation of Subcommittee VII the committee recommends for immediate adoption a revision of the Standard Methods of Determining Weight and Uniformity of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 – 33),[4] and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that this revision may be referred to letter ballot of the Society. This revision, which is given in detail below, omits from the methods all reference to the Preece test as more up-to-date information has been incorporated in the Methods of Test for Uniformity of Coating by the Preece Test (Copper Sulfate Dip) on Zinc-Coated (Galvanized) Iron or Steel Wire (A 191 – 38) and on Steel Castings and Forgings, Gray-Iron and Malleable-Iron Castings (A 208 – 38 T):

Title.—Change to read as follows by the omission of the words in brackets:

Standard Methods of Determining Weight [and Uniformity] of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles.

Appendix.—Omit the section on "Test for Uniformity of Coating on Zinc-Coated Articles" together with the two footnotes pertaining to this section.

On the recommendation of Subcommittee VI the committee is presenting for publication as tentative a revision of the Standard Specifications for Zinc-Coated (Galvanized) Iron or Steel Wire Strand (Cable) (A 122 – 33)[5] (A.S.A. G8.6-1935) in the form of new Tentative Specifications for Zinc-Coated Steel Wire Strand ("Galvanized" and "Extra Galvanized")[1] which are intended to replace, when adopted, the present standard. Three wire strand and a fifth strength classification called "utilities grade" have been included in the new specifications.

IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARDS

On the recommendation of Subcommittee VI the committee recommends that the following two tentative specifications be approved for reference to letter ballot of the Society for adoption as standard, without revision:

Tentative Specifications for:

Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (A 116 – 37 T),[6] to replace the present Standard Specifications A 116 – 30,[7] and
Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 – 37 T),[6] to replace the present Standard Specifications A 121 – 30.[7]

V. WITHDRAWAL OF STANDARDS

On the recommendation of Subcommittee VII the committee recommends that the Standard Methods of Determining Weight of Coating on Tin, Terne, and Lead-Coated Sheets (A 91 – 24)[8] be withdrawn since these methods have become outmoded.

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[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, pp. 682, 684, 686 (1935); also 1938 Book of A.S.T.M. Tentative Standards, pp. 211, 213, 215.

[4] 1936 Book of A.S.T.M. Standards, Part I, p. 397.

[5] 1936 Book of A.S.T.M. Standards, Part I, p. 381.

[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, pp. 646, 643 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 198, 201.

[7] 1936 Book of A.S.T.M. Standards, Part I, pp. 368 362.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 123 members; 72 members returned their ballots, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. New Tentative Standards			
Spec. for Zinc-Coated Steel Wire Strand, (Class B and Class C Coatings)	52	2	18
Methods of Test for Local Thickness of Electrodeposited Coatings on Steel	52	0	20
II. Revisions of Tentative Standards			
Spec. for Electrodeposited Coatings of Zinc on Steel (A 164 - 35 T)	52	0	20
Spec. for Electrodeposited Coatings of Cadmium on Steel (A 165 - 35 T)	46	0	26
Spec. for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 35 T)	45	0	27
III. Revisions of Standards			
Methods of Determining Weight and Uniformity of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 - 33), immediate adoption	64	2	6
Spec. for Zinc-Coated (Galvanized) Iron or Steel Wire Strand (Cable) (A 122 - 33)	57	0	15
IV. Adoption of Tentative Standards as Standard			
Spec. for Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (A 116 - 37 T)	56	0	16
Spec. for Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 - 37 T)	55	0	17
V. Withdrawal of Standard			
Methods of Determining Weight of Coating on Tin, Terne and Lead-Coated Sheets (A 91 - 24)	49	1	22

ACTIVITIES OF SUBCOMMITTEES

Subcommittee III on Inspection of Annapolis Tests (E. S. Taylerson, chairman).—The specimens of No. 22 gage copper-bearing and non-copper-bearing corrugated black sheets that have been exposed at Annapolis, Md., since October 17, 1916, were inspected on May 2 and on October 10, 1938. At the May inspection it was found that seven sheets had failed, namely, B1, C5, C26, H5, T4, T7, and T14. On October 10 it was found that sheets V6, V7, and V13 had failed. A summary of the failures to date is given in the accompanying Table II.

Subcommittee V on Total Immersion Tests (W. J. Jeffries, chairman).—The biennial inspection of the riveted test plates exposed to sea water at Portsmouth, N. H., and Key West, Fla., was made and copper replicas prepared. Photographs have been made of the plates for study by the subcommittee. All of the No. 16 gage sheet steel specimens immersed in sea water at Portsmouth and Key West have now failed. In view of this fact, the copper and non-copper-bearing steel tubes and the copper-bearing tubes assembled in crates, which were exposed to sea water in the same locations, have been removed from the tests and forwarded to the chairman for examination. The subcommittee expects to submit next year

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[8] 1936 Book of A.S.T.M. Standards, Part I, p. 404.

TABLE II.—RECORD OF FAILURES IN ATMOSPHERIC EXPOSURE TESTS AT ANNAPOLIS OF NO. 22-GAGE COPPER-BEARING AND NON-COPPER-BEARING CORRUGATED BLACK SHEETS.

Sheets Exposed October 17, 1916. Inspections Made Semiannually from 1917 to 1939.

Group	Designation	Series	Average Analysis, per cent						Number of Sheets in Test[a]	Life of Each Failed Sheet in Years																Number of Sheets in Test[a]	Number of Sheets Failed	Average Life of Sheets in Years	Group
			Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper																					
Z.....	Open-hearth steel	B	0.032	0.32	0.063	0.042	.....	0.019	3	13.5	17.0	19.0	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	16.5	......Z
O.....	Open-hearth steel	A	0.121	0.536	0.008	0.030	0.249	0.020	12	7.0	9.0	9.0	9.0	9.0	9.5	10.0	10.0	11.0	11.0	13.0	17.0	..	..	..	..	12	12	10.4	......O
B.....	Open-hearth steel	A	0.09	0.38	0.017	0.062	0.036	0.084	3	20.0	20.5	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	2	....	......B
M.....	Open-hearth steel	B	0.093	0.419	0.013	0.041	0.011	0.185	14	20.0	20.5	*	*	*	*	*	*	*	*	*	*	*	*	..	..	14	2	....	......M
B.....	Open-hearth steel	A	0.06	0.27	0.014	0.053	0.006	0.187	9	19.5	20.0	21.5	22.0	*	*	*	*	*	..	..	..	..	..	..	..	9	4	....	......B
Z.....	Open-hearth steel	B	0.067	0.351	0.045	0.052	0.003	0.187	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	....	......Z
T.....	Open-hearth steel	B	0.083	0.313	0.009	0.020	0.005	0.227	14	19.5	19.5	19.5	21.5	21.5	21.5	*	*	*	*	*	*	*	*	..	..	14	6	....	......T
K.....	Open-hearth steel (acid)	A	0.107	0.447	0.091	0.046	0.004	0.237	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16	0	....	......K
H.....	Open-hearth steel	A	0.069	0.387	0.016	0.027	0.004	0.244	11	19.5	21.0	21.5	*	*	*	*	*	*	*	*	..	..	..	..	..	11	3	....	......H
Z.....	Open-hearth steel	B	0.065	0.35	0.050	0.059	0.003	0.264	2	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	0	....	......Z
Z.....	Open-hearth steel	B	0.073	0.42	0.052	0.054	Trace	0.641	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	....	......Z
S.....	Open-hearth iron	B	0.02	0.023	0.006	0.022	0.004	0.022	14	7.0	8.0	8.5	9.0	9.5	10.0	11.0	11.5	11.5	12.5	12.5	12.5	12.5	12.5	..	..	14	14	10.6	......S
D.....	Open-hearth iron	A	0.02	0.026	0.004	0.022	0.002	0.024	6	16.0	16.0	16.0	19.5	19.5	*	..	..	..	..	..	..	..	..	..	..	6	5	....	......D
X.....	Open-hearth iron	B	0.021	0.055	0.007	0.031	0.004	0.027	14	10.5	13.0	13.5	14.5	14.5	16.0	16.0	16.5	16.5	17.0	17.5	17.5	18.0	19.0	..	..	14	14	15.7	X
C.....	Open-hearth iron	A	0.01	0.028	0.002	0.027	0.002	0.141	3	17.5	20.5	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	2	....	C
C.....	Open-hearth iron	A	0.015	0.028	0.006	0.036	0.003	0.194	9	16.5	16.5	18.5	19.0	19.0	20.0	20.5	21.5	21.5	..	..	..	..	..	..	..	9	9	19.2	C
U.....	Open-hearth iron	B	0.017	0.074	0.008	0.037	0.005	0.260	13	15.5	16.5	19.0	19.0	19.0	19.0	19.0	19.5	20.0	20.0	21.0	21.0	*	..	..	..	13	12	....	......U
V.....	Open-hearth iron	B	0.018	0.051	0.007	0.021	0.005	0.304	14	17.0	17.0	17.5	18.5	18.5	19.0	20.0	20.0	20.5	21.0	22.0	22.0	*	*	..	..	14	12	....	V
A.....	Bessemer steel	A	0.038	0.386	0.089	0.040	0.007	0.014	15	15.5	16.5	16.5	17.0	17.0	17.0	18.0	19.0	19.0	19.5	19.5	19.5	19.5	19.5	20.0	..	15	15	18.2	......A
Z.....	Bessemer steel	B	0.063	0.41	0.102	0.044	0.009	0.013	3	11.5	11.5	11.5	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	11.5	......Z
Z.....	Bessemer steel	B	0.077	0.44	0.095	0.036	0.003	0.140	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	....	......Z
I.....	Bessemer steel	A	0.041	0.365	0.097	0.068	0.008	0.252	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16	0	....	I
Z.....	Bessemer steel	B	0.058	0.37	0.093	0.043	0.009	0.269	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	....	......Z
Z.....	Bessemer steel	B	0.055	0.38	0.110	0.046	.....	0.527	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	....	......Z
Y.....	Wrought iron	B	0.03	0.055	0.139	0.021	0.218	0.020	3	18.0	19.5	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	2	....	......Y
E.....	Wrought iron	A	0.033	0.034	0.114	0.021	0.134	0.283	11	19.5	20.5	21.0	21.0	*	*	*	*	*	*	*	..	..	..	..	..	11	4	....	......E
							Total:.........		220																Total....	220	124		

* Indicates unfailed sheets.

[a] The number of sheets in the test indicated in this table is less in some instances than the number shown in similar tables in earlier reports because certain sheets were discarded due to mechanical damage.

complete tables on the failures of the sheet specimens with an analysis of the data obtained.

Subcomittee VI on Specifications for Metallic-Coated Products (T. R. Galloway, chairman).—The activities of this subcommittee, with regard to specifications, are covered generally by the recommendations affecting standards shown earlier in this report. The other tentative and standard specifications sponsored by this subcommittee will be continued in their present status for another year. The proposed revision of the Standard Specifications for Galvanized Line Wire (A 111 - 33) and for Galvanized Tie Wire (A 112 - 33) to cover heavier coatings on telephone and telegraph line and tie wires will probably be abandoned because of lack of demand for such a revision. A study is being made of the Tentative Specifications for Zinc Coating on Hardware and Fastenings (A 153 - 33 T) to determine whether to continue this as a single specification or to divide it into several specifications. The subgroup studying the need for revision of the Specifications for Chain-Link Fence Fabric (A 117 - 33) is not yet ready to report.

Subcommittee VII on Methods oj Testing (R. W. Baker, Chairman).—The activities of this subcommittee with regard to specifications are covered generally by the recommendations affecting standards given earlier in this report. It has been decided to appoint a subgroup to study the desirability of embodying in one document the present material on the Preece test included in the Methods of Test for Uniformity of Coating by the Preece Test (Copper Sulfate Dip) on Zinc-Coated (Galvanized) Iron or Steel Wire (A 191 - 38) and on Steel Castings and Forgings, Gray-Iron and Malleable Iron Castings (A 208 - 38 T), and to include methods for making the Preece test for uniformity of zinc coating on such other materials as bolts, nuts, and screws not now specifically covered by any A.S.T.M. specifications. If the report is favorable, this group will proceed to prepare such test methods.

Subcommittee VIII on Field Test of Metallic Coatings (R. F. Passano, chairman).—This subcommittee has continued its inspections in the field of the atmospheric exposure tests under way on galvanized sheets, metallic-coated hardware, structural shapes and tubular goods, and wire and wire products. It does not appear necessary to publish this year a report on any of the tests under way except the work of the Wire Test Inspection Group. The referee test data and the test results on the first specimens removed from the test racks and returned for tests have now become available. This material is so voluminous that it has been appended hereto in a separate report.

This report has been submitted to letter ballot of the committee which consists of 123 members; 72 members returned their ballots, of whom 67 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. H. FINKELDEY,
Chairman.

T. R. GALLOWAY,
Secretary.

REPORT OF SUBCOMMITTEE VIII ON FIELD TESTS OF METALLIC COATINGS

At the time Subcommittee VIII on Field Tests of Metallic Coatings was organized, opinions were expressed that the protection given by a coating at any location depended on (1) the kind of coating, (2) the method by which the coating was applied, (3) the weight of coating, and (4) the shape of the base article which the coating was to protect. There was little, if any, information on the relative importance of these several points. These subjects of investigation for the subcommittee were divided into three projects for convenience in execution.

The first exposure made by the subcommittee in 1926 was designed to produce information concerning weight of coating (item 3 above) on one shape of base article, corrugated sheets. In this, Subcommittee VIII was following the previous work which Committee A-5 had done on uncoated steel sheets through its Subcommittee III.

In 1929, a set of miscellaneous shapes was exposed, with coatings of aluminum, cadmium, lead, and zinc.

Where possible, the shapes were coated by various methods. This exposure (usually referred to briefly as the Hardware Test) was intended to produce information on items 1, 2, and 4 above, namely, kind of coating, method by which the coating was applied, and shape of the article which carried the coating. It is unfortunate that in a program so varied, the weights of coating could not be as systematically planned and precisely determined as now appears desirable.

Progress reports on the sheet and hardware tests have been made by the inspection sub-subcommittees annually. Their observations, summarized to a certain extent, may be found in the reports of this subcommittee for 1936 and 1938. The inspection groups have continued their observations at regular intervals. Since change of condition on their samples is now relatively slow, their work does not require that detail be set forth in this report.

In 1936, Subcommittee VIII completed the outdoor placement of a very comprehensive group of samples of wire and wire products. The majority of the specimens are pieces of straight wire, but there is also included a planned collection of specimens of farm field fence, barbed wire, chain link fence, and strand. The test involves about 1000 specimens at each of eleven locations.

The test is planned primarily for the evaluation of zinc coatings. The specimens include coatings of this metal applied by all of the several processes known to have been commercially available at the time the test was started. The program provides for determining the rate of loss of zinc coatings on different sizes of wire (weight loss specimens), and intercomparing the life of heavy gage wires carrying light zinc coatings with that of light gage wires carrying heavy zinc coatings. The forthcoming results will also compare the life of these zinc-coated wires with copper covered wire, lead-coated wire, and uncoated corrosion-resistant steel products. The life of the wire and wire products is determined partly by visual inspection to note incidence of rust and partly by tensile strength tests of samples removed periodically after rusting has started.

The wire test is probably the best and most comprehensively planned of any of the projects thus far undertaken by Subcommittee VIII. Nearly all of the samples under test are very completely characterized by micrographs, physical tests, chemical analyses of the base metal, and in the case of zinc coatings by chemical analyses of the coatings. The eleven locations at which test specimens are exposed are widely separated geographically, and range from very severe to very mild exposure.

It was considered necessary in this particular wire exposure test to test types of material. Since it was intended that the identity of the samples as to source be lost, it was necessary that a number of detailed determinations be made on the wire samples. This detailed information on properties and composition is given in the accompanying report and is really more significant than if they were identified primarily by their brand names.

The 1937 report of Subcommittee VIII set forth the plan of the wire test in some detail, and the current report is devoted largely to the identification of the specimens in the test. This is followed by a brief summary of the observations which have been made to date.

It would be impossible to acknowledge the contributions of everyone who has had a hand in this large undertaking. The work has been directed successively by Mr. F. F. Farnsworth, Mr. H. E. Smith, Mr. W. H. Finkeldey, and Mr. C. D. Hocker. This supervision would have gone for naught if it had not been for the cooperation of wire producers and the agricultural colleges. To these persons the subcommittee expresses its gratitude. The effort which has been put into this project is expected to produce more extensive information than is available anywhere else.

This report of Subcommittee VIII has been submitted to the members of the subcommittee for letter ballot. The subcommittee consists of 51 members, 30 members returned their ballots, of whom 25 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the subcommittee,

R. F. PASSANO,
Chairman.

REPORT ON ORIGINAL CHARACTERISTICS OF WIRE AND WIRE PRODUCTS INVOLVED IN FIELD EXPOSURE TESTS

Referee Tests Made under the Supervision of the National Bureau of Standards

This section constitutes the final report of the Wire Test Committee and contains a record of the physical and chemical properties of wire and wire product specimens submitted to the committee by the suppliers, together with the methods employed in determining their characteristics.

In characterizing the test materials, the cooperation of the National Bureau of Standards was made possible through the considerable efforts of Dr. L. J. Briggs, Director, and Dr. H. S. Rawdon, Chief of the Division of Metallurgy. The testing work was done by Messrs. Thurston D. Brown and Alfred L. Finn, Research Associates. The methods employed for determining the original characteristics of the test specimens were selected or developed by the research associates and agreed to by a section of the Wire Test Committee on Test Methods, comprising F. M. Crapo, C. C. Crane, W. H. Finkeldey (chairman), F. C. Elder, C. A. Kellogg, and L. H. Winkler.

It is with sincere appreciation that the committee acknowledges the tremendous assistance given to it during this stage of the program by the National Bureau of Standards. While the salaries of the research associates were taken from committee funds, all of the supervision, laboratory facilities, supplies, and storage space required at the Bureau for this phase of the work were furnished gratis to the committee.

There follows an index of the specimens, indicating the tables, either Table I, Table II, or Table III, in which the data are presented for the various types of wire exposed. Unfabricated wire, barbed wire specimens and farm field fence wire are covered in Table I, as indicated. Wire strand specimens are covered in Table II and chain link fence specimens in Table III.

INDEX OF SPECIMENS

Unfabricated Wire Specimens

Wire Lot	Table	Wire Lot	Table	Wire Lot	Table	Wire Lot	Table	Wire Lot	Table	Wire Lot	Table
No. 001	I-N	No. 101	I-M	No. 200	I-M	No. 300	I-M	No. 400	I-M	No. 501	I-M
No. 002	I-N	No. 102	I-M	No. 202	I-M	No. 302	I-M	No. 401	I-M	No. 506	I-L
No. 003	I-N	No. 105	I-M	No. 205	I-L	No. 305	I-L	No. 405	I-L	No. 507	I-L
No. 004	I-N	No. 106	I-L	No. 206	I-L	No. 306	I-L	No. 406	I-L	No. 510	I-A
No. 005	I-N	No. 115	I-B	No. 215	I-B	No. 315	I-B	No. 410	I-A	No. 511	I-A
No. 006	I-N	No. 117	I-B	No. 216	I-B	No. 316	I-B	No. 411	I-A	No. 512	I-A
No. 007	I-N	No. 125	I-D	No. 217	I-B	No. 317	I-B	No. 412	I-A	No. 520	I-C
No. 008	I-N	No. 127	I-D	No. 225	I-D	No. 325	I-D	No. 421	I-C	No. 521	I-C
No. 009	I-N	No. 135	I-F	No. 226	I-D	No. 326	I-D	No. 422	I-C	No. 522	I-C
No. 015	I-N	No. 138	I-F	No. 227	I-D	No. 327	I-D	No. 423	I-C	No. 530	I-E
		No. 139	I-F	No. 228	I-D	No. 329	I-D	No. 430	I-E	No. 531	I-E
		No. 148	I-H	No. 235	I-F	No. 335	I-F	No. 431	I-E	No. 540	I-G
		No. 149	I-H	No. 236	I-F	No. 336	I-F	No. 432	I-E	No. 541	I-G
		No. 151	I-J	No. 237	I-F	No. 337	I-F	No. 440	I-G	No. 542	I-G
No. 021	I-P			No. 238	I-F	No. 338	I-F	No. 441	I-G	No. 543	I-G
No. 022	I-P			No. 239	I-F	No. 345	I-H	No. 442	I-G	No. 551	I-J
				No. 245	I-H	No. 346	I-H	No. 443	I-G	No. 552	I-J
				No. 246	I-H	No. 347	I-H	No. 444	I-G		
				No. 247	I-H	No. 348	I-H	No. 450	I-J		
No. 040	I-O			No. 248	I-H	No. 350	I-J	No. 451	I-J		
No. 041	I-O			No. 250	I-J	No. 351	I-J				
No. 042	I-O			No. 251	I-J	No. 352	I-J			No. 800	I-I
No. 043	I-O			No. 252	I-J	No. 397	I-K			No. 801	I-I
				No. 282	I-C						
				No. 298	I-K						
				No. 299	I-K						

Barbed Wire Specimens

Barbed Wire	Table	Wire Lot	Barbed Wire	Table	Wire Lot	Barbed Wire	Table	Wire Lot
No. 025	I-P	No. 021	No. 422	I-C	No. 421	No. 445	I-G	....
No. 045	I-O	No. 042	No. 430	I-E	No. 431	No. 446	I-G	....
			No. 431	I-E	No. 430	No. 447	I-J	....
No. 410	I-A	No. 410	No. 432	I-E	No. 432	No. 450	I-J	....
No. 411	I-A	....	No. 441	I-G	No. 442	No. 451	I-J	No. 451
No. 412	I-A	No. 412	No. 442	I-G	No. 441	No. 452	I-J	No. 450
No. 420	I-C	No. 423	No. 443	I-G	No. 443	No. 494	I-J	....
No. 421	I-C	....						

Farm Field Fence Specimens[a]

(1) Fence (2) Int. (3) T-B	Table	(1) Fence (2) Int.	Table	(3) T-B	(1) Fence (2) Int.	Table	(1) Fence (2) Int.	Table	T-B Wires in Fence Table	(3) T-B
No. 205[b]	I-L	No. 305	I-L	No. 206	No. 405	I-L	No. 505	I-L	I-L	No. 306
No. 206	I-L	No. 306	I-L	No. 207	No. 406	I-L	No. 506	I-L	I-L	No. 305
No. 215	I-B	No. 315	I-B	No. 215	No. 410	I-A	No. 510	I-A	I-B	No. 316
No. 216	I-B	No. 316	I-B	No. 216	No. 411	I-A	No. 511	I-A	I-B	No. 317
No. 225	I-D	No. 317	I-B	No. 217	No. 412	I-A	No. 512	I-A	I-B	No. 315
No. 227	I-D	No. 325	I-D	No. 228	No. 421	I-C	No. 520	I-C	I-D	No. 325
No. 228	I-D	No. 326	I-D	No. 226	No. 422	I-C	No. 521	I-C	I-D	No. 329
No. 235	I-F	No. 327	I-D	No. 225	No. 423	I-C	No. 522	I-C	I-D	No. 327
No. 236	I-F	No. 335	I-F	No. 237	No. 430	I-E	No. 530	I-E	I-F	No. 338
No. 237	I-F	No. 336	I-F	No. 238	No. 431	I-E	No. 531	I-E	I-F	No. 335
No. 238	I-F	No. 337	I-F	No. 235	No. 432	I-E	No. 532	I-E	I-F	No. 337
No. 245	I-H	No. 338	I-F	No. 236	No. 433	I-E	No. 540	I-G	I-H	No. 348
No. 246	I-H	No. 345	I-H	No. 247	No. 440	I-G	No. 541	I-G	I-H	No. 345
No. 247	I-H	No. 346	I-H	No. 245	No. 441	I-G	No. 542	I-G	I-H	No. 346
No. 248	I-H	No. 347	I-H	No. 246	No. 442	I-G	No. 543	I-G	I-H	No. 347
No. 252	I-J	No. 348	I-H	No. 248	No. 443	I-G				
No. 298	I-J	No. 350	I-J	No. 252			No. 001	I-N	I-N	No. 001
		No. 352	I-J	No. 251			No. 002	I-N	I-N	No. 002
		No. 397	I-K	No. 298			No. 003	I-N	....	....
							No. 020[c]	I-P	I-P	No. 022
							No. 040[c]	I-O	I-O	No. 041

Wire strand specimens: All in Table II.
Chain link fence specimens: All in Table III.

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[a] Abbreviations: int. = interior line and stay wires.
T-B = top and bottom line wires.

[b] All 200 series fences have the same wire in all parts of the fence. All 300 series fences have 200 series wires for top and bottom line wires whose detailed characteristics are reported in the same table as the Int. wires. All 400 series fences have top and bottom line wires not represented in other test specimens and not reported in the detailed analyses. All 500 series fences have 300 series wires for top and bottom line wires whose characteristics are reported in the tables shown.

[c] The interior wires of these two fences are Nos. 021 and 041, respectively.

MICROGRAPHS AND CHARACTERISTICS OF SPECIMENS OF UNFABRICATED WIRE, FARM FIELD FENCE, AND BARBED WIRE

(Arranged in a Series of Tables, I-A to I-P)

Table I-A shows the data on specimens which were furnished with intended coatings of 0.20 to 0.30 oz. per sq. ft. of zinc coating; Table I-B covers specimens with intended coatings of 0.25 to 0.35 oz. per sq. ft.; each of Tables I-C to I-K covers a particular intended zinc-coating range; Tables I-L and I-M cover uncoated mild steel wire specimens; Table I-N shows data on uncoated corrosion-resistant steel wire specimens; Tables I-O and I-P cover lead-coated and copper-covered wire specimens, respectively.

Each table includes data on unfabricated wire, farm fence, and usually on barbed wire. Each table has the following features:

(*a*) The first columns show wire lot numbers. Wire from a given lot may be under test in specimens of fence, or barbed wire, or unfabricated wire. Every supplier submitting samples of farm fence or barbed wire for test was supposed to submit a coil (or coils) of unfabricated wire identified as being from the same lots of wire as the lots that had been used in the fabrication of his fence and barbed wire samples. This arrangement was adhered to by suppliers in nearly all cases, but there may be a few exceptions—cases in which the engineer of tests asked for supplementary samples of unfabricated wire and has received material known to be similar but probably not identical. In Tables I-A to I-P, it is assumed that there are no exceptions to the intended arrangement. Every wire lot is indicated as being under test as intended and as listed in the tabulations alongside the photographs.

(*b*) A typical table, as I-A, lists 6 wire lot numbers (Nos. 510, 511, 512, 410, 411, and 412). These comprise all of the wire lots in the test which were furnished with an intended weight of zinc coating in the range of 0.20 to 0.30 oz. per sq. ft. All of the data from laboratory tests of these six wire lots are listed in Table I-A.

(*c*) Each of Tables I-A to I-K is divided into two parts. The first part tabulates the results of tension tests, and chemical analyses of the base metals and of the coatings.

The second part lists the photomicrographs, and alongside of them lists all of the test information that might have a relation to the appearance of the photograph (weight of coating, Preece test, coating thickness variation as determined by microexamination, wrap test performance, and iron content of the coating.)

(*d*) The wire lot numbering system means the following: If a wire lot is, for example, No. 512, wire from this lot was used in unfabricated wire specimen B-512 which is under test; wire from this same lot was used for the interior line and stay wires of farm fence A-512. (The A and B prefixes are usually dropped in this report.)

(*e*) All test results were obtained on samples cut from coils of unfabricated wire except where specifically identified as having a farm field fence or barbed wire specimen origin.

(*f*) The wrap test performances reported in the tables as "checks," "cracks," "flaked," and "peeled" are illustrated by typical photographs following Table III.

(*g*) Every individual coating weight test result and Preece test result is listed and is identified with the origin of the sample tested, that is, whether the sample tested was cut from a coil of unfabricated wire, or from the interior or top or bottom line wire of a particular fence, or from a barbed wire specimen.

(*h*) Tables I-A to I-M (those covering zinc-coated or uncoated mild steel specimens) report analyses of the base metals for 7 elements. Analyses were also made for nickel and for molybdenum, but the results are not reported because they show no significant differences among the samples. The molybdenum contents were in all cases less than 0.02 per cent; the nickel contents were in all cases less than 0.10 per cent.

Tables I-A to I-K (those covering zinc-coated specimens) report analyses of the coatings for 4 elements. Analyses were also made for tin, but the results are not reported because they show no significant differences among the samples; all had a tin content less than 0.01 per cent.

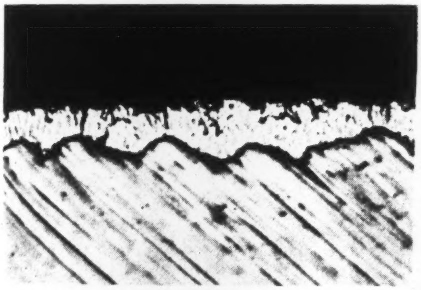
(*i*) Scale of photomicrographs:

Specimens	Original Magnification	Reduced in Reproduction
All zinc coated	750	To $\frac{3}{4}$ original size
All corrosion-resistant steel	500	
All lead coated	500	
All copper covered	350	

TABLE I - A.—ZINC COATED SPECIMENS: 0.20 TO 0.30 OZ. PER SQ.FT., NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 510	500	1.8	111 100	113 600	0.23	0.08	0.09	8.7	0.11	0.43	0.015	0.026	0.13	0.24	0.03
No. 511	280	20.5	64 000	65 800	N.D.	N.D.	0.07	9.2	0.13	0.52	0.013	0.021	0.07	0.23	0.04
No. 512	320	19.1	71 000	73 300	0.18	N.D.	0.13	6.4	0.13	0.47	0.017	0.035	0.18	0.23	0.02
No. 410	470	18.0	61 000	62 700	0.22	N.D.	0.12	6.5	0.13	0.47	0.019	0.039	0.18	0.22	0.02
No. 411	630	6.0	84 200	85 400	N.D.	N.D.	0.08	6.9	0.12	0.50	0.023	0.029	0.15	0.22	0.03
No. 412	840	7.2	107 500	108 900	0.27	0.09	0.10	8.7	0.10	0.42	0.022	0.027	0.11	0.24	0.03
No. C - 411	(Barbed Wire): Coating, 0.24 oz. Zn per sq.ft. Preece dips* withstood: 2				0.32	N.D.	0.08	7.8	0.13	0.47	0.019	0.039	0.18	0.22	0.02

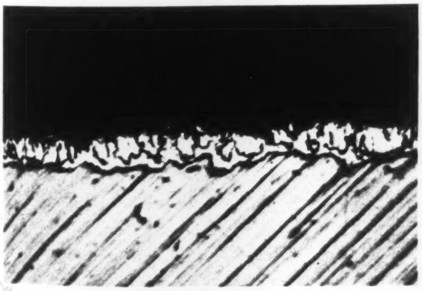
N.D. = not detected—that is, less than about 0.01 per cent.



Wire lot No. 510; Gage, 14.5
Coating weight, 0.29 oz. per sq.ft.

In Exposure Test as:	Determinations: Coating Weights	Determinations: Preece Dips* Withstood
Unfabricated sample No. 510 Interior of fence No. 510	0.29, 0.29 0.29	2, 1, 2, 3, 2 2, 2, 2, 2, 2
	Avg. 0.29	

Coating thickness, in.: Min. 0.00031, Max. 0.0005
Wrap test performance, good
Iron content of coating, 8.7 per cent



Wire lot No. 511; Gage, 14.5
Coating weight, 0.24 oz. per sq.ft.

Unfabricated sample No. 511 Interior of fence No. 511	0.24, 0.24 0.23	2, 2, 2, 2, 2 2, 2, 2, 2, 2
	Avg. 0.24	

Coating thickness, in.: Min. 0.00031, Max. 0.00044
Wrap test performance, good
Iron content of coating, 9.2 per cent

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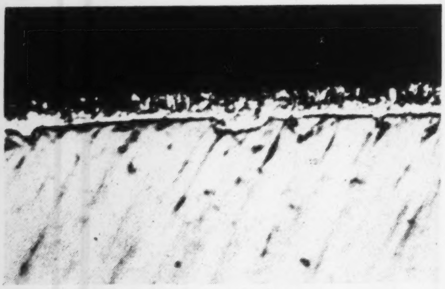
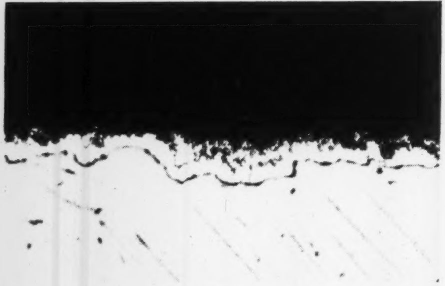
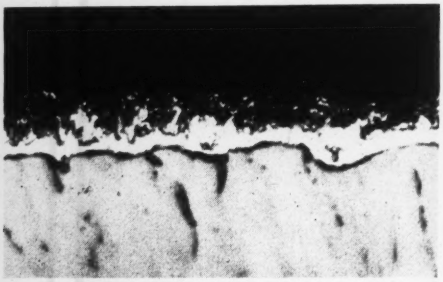
*See note at the end of Table I - K.

TABLE I - A.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 512; Gage, 14.5 Coating weight, 0.27 oz. per sq.ft.	Unfabricated sample No. 512 Interior of fence No. 512	0.27, 0.27 0.27	2, 2, 2, 2, 2 3, 3, 3, 3, 3
		Avg. 0.27	
	Coating thickness, in.: Min. 0.00025, Max. 0.00075 Wrap test performance, good Iron content of coating, 6.4 per cent		
 Wire lot No. 410; Gage, 12.5 Coating weight, 0.30 oz. per sq.ft.	Unfabricated sample No. 410 Interior of fence No. 410 Barbed wire No. 410	0.25, 0.24 0.38, 0.39 0.27	0, 2, 2, 2, 2 2, 2, 2 2, 2, 2, 2, 2
		Avg. 0.30	
	Coating thickness, in.: Min. 0.00025, Max. 0.0005 Wrap test performance, good Iron content of coating, 6.5 per cent		
 Wire lot No. 411; Gage, 12.5 Coating weight, 0.28 oz. per sq.ft.	Unfabricated sample No. 411 Interior of fence No. 411	0.29, 0.28 0.28	3, 3, 3, 3, 3 2, 2, 3
		Avg. 0.28	
	Coating thickness, in.: Min. 0.00031, Max. 0.00063 Wrap test performance, good Iron content of coating, 6.9 per cent		

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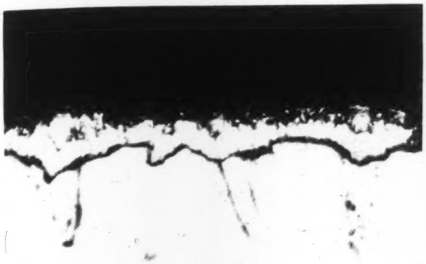
* See note at the end of Table I - K.

TABLE I - A.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 412; Gage, 12.5
Coating weight, 0.29 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 412	0.31, 0.30	2, 2, 2, 3, 3
Interior of fence No. 412	0.30	3, 3, 3, 3
Barbed wire No. 412	0.27	3, 3, 3
	Avg. 0.29	

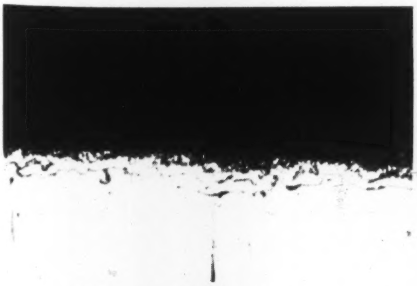
Coating thickness, in.: Min. 0.00025, Max. 0.0005
Wrap test performance, good
Iron content of coating, 7.8 per cent

* See note at the end of Table I - K.

TABLE I - B.—ZINC COATED SPECIMENS: 0.25 TO 0.35 OZ. PER SQ.FT. NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 315.....	890	13.3	77 100	78 500	0.26	N.D.	0.14	5.7	0.13	0.47	0.016	0.034	0.17	0.22	0.02
No. 316.....	1110	8.2	98 400	100 200	0.11	0.10	0.10	7.9	0.10	0.45	0.014	0.026	0.13	0.25	0.03
No. 317.....	780	14.5	68 900	71 000	N.D.	N.D.	0.04	7.9	0.13	0.49	0.011	0.028	0.18	0.23	0.02
No. 215.....	1200	14.7	70 800	72 100	0.31	0.12	0.13	4.8[a]	0.12	0.43	0.016	0.034	0.18	0.21	0.02
No. 216.....	1630	8.5	91 900	93 500	0.30	N.D.	0.10	8.1	0.09	0.45	0.015	0.025	0.13	0.24	0.03
No. 217.....	1080	10.8	63 000	63 700	N.D.	N.D.	0.05	7.1	0.09	0.42	0.012	0.028	0.01	0.22	0.03
No. 115.....	2690	7.8	92 900	94 200	0.41	0.08	0.06	8.3	0.10	0.45	0.014	0.023	0.15	0.25	0.03
No. 117.....	2230	10.7	77 500	78 700	0.22	N.D.	0.14	6.0	0.13	0.41	0.062	0.035	0.01	0.24	0.05

N.D. = not detected—that is, less than 0.01 per cent.
[a] Check analysis of iron content of coating, 6.3 per cent.



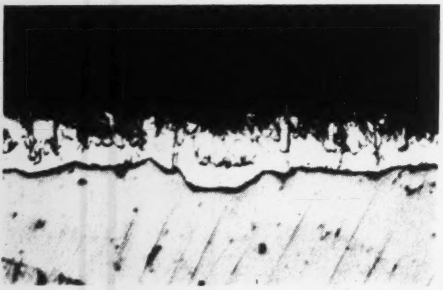
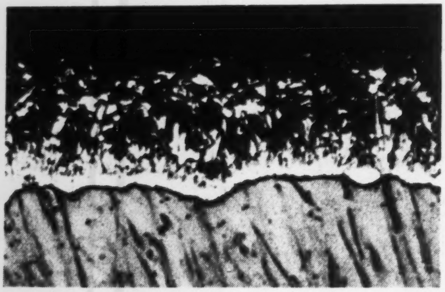
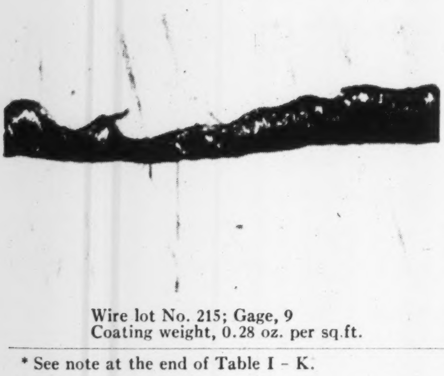
Wire lot No. 315; Gage, 11
Coating weight, 0.25 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 315	0.25, 0.26	1, 2, 2, 2, 2
Interior of fence No. 315	0.25	2, 2, 2
Top of fence No. 512	0.25	3, 3, 3, 3, 3
Bottom of fence No. 512	0.26	2, 2, 2, 2, 2
	Avg. 0.25	

Coating thickness, in.: Min. 0.00025, Max. 0.00088
Wrap test performance, good
Iron content of coating, 5.7 per cent

* See note at the end of Table I - K.

TABLE I - B.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 316; Gage, 11 Coating weight, 0.32 oz. per sq.ft.	Unfabricated sample No. 316 Interior of fence No. 316 Top of fence No. 510 Bottom of fence No. 510	0.33, 0.32 0.31 0.32 0.33 Avg. 0.32	3, 3, 3, 3, 3 4, 4, 4, 4, 4 3, 3, 3, 3, 3 2, 2, 3, 3, 3
	Coating thickness, in.: Min. 0.00044, Max. 0.00069 Wrap test performance, good Iron content of coating, 7.9 per cent		
 Wire lot No. 317; Gage, 11 Coating weight, 0.38 oz. per sq.ft.	Unfabricated sample No. 317 Interior of fence No. 317 Top of fence No. 511 Bottom of fence No. 511	0.43, 0.43, 0.48 0.47, 0.47, 0.47 0.34 0.37 0.36 Avg. 0.38	3, 3, 3, 3, 3 3, 4, 5, 5, 5 4, 4, 4, 4, 4 4, 4, 4, 4, 4
	Coating thickness, in.: Min. 0.00025, Max. 0.001 Wrap test performance, checks Iron content of coating, 7.9 per cent		
 Wire lot No. 215; Gage, 9 Coating weight, 0.28 oz. per sq.ft.	Unfabricated sample No. 215 Interior fence No. 215 Top of fence No. 215 Bottom of fence No. 215 Top of fence No. 315 Bottom of fence No. 315	0.26, 0.28, 0.29 — 0.25 0.25 0.33 0.29 Avg. 0.28	2, 2, 2 2, 2 2, 2, 2, 2 2, 2, 2, 2 2, 2, 2 2, 2, 2
	Coating thickness, in.: Min. 0.00063, Max. 0.00188 Wrap test performance, good Iron content of coating, 4.8 per cent Check analyses, 6.3 per cent		

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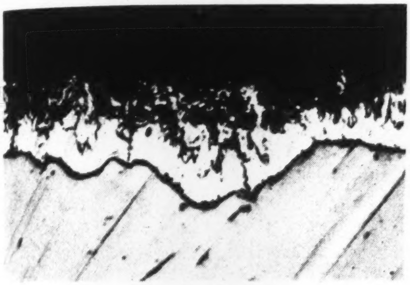
* See note at the end of Table I - K.

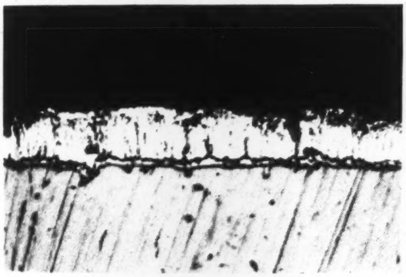
TABLE I - B.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 216; Gage, 9
Coating weight, 0.30 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 216	0.30, 0.31, 0.32	2, 2, 2, 3, 3
Interior of fence No. 216	—	3, 3, 3, 3
Top of fence No. 216	0.30	3, 3, 3, 3
Bottom of fence No. 216	0.31	3, 3, 3, 3
Top of fence No. 316	0.27	3, 3, 3, 3
Bottom of fence No. 316	0.29	4, 4, 4, 4
	Avg. 0.30	

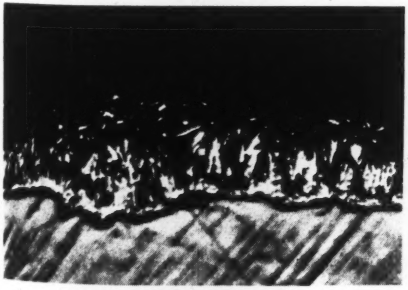
Coating thickness, in.: Min. 0.00031, Max. 0.00075
Wrap test performance, good
Iron content of coating, 8.1 per cent



Wire lot No. 217; Gage, 9
Coating weight, 0.36 oz. per sq.ft.

Unfabricated sample No. 217	0.28, 0.29, 0.30	2, 3, 3, 3, 3
Top of fence No. 317	0.40	5, 5, 5, 5, 5
Bottom of fence No. 317	0.39	5, 5, 5, 5, 5
	Avg. 0.36	

Coating thickness, in.: Min. 0.0005, Max. 0.00063
Wrap test performance, good
Iron content of coating, 7.1 per cent



Wire lot No. 115; Gage, 6
Coating weight, 0.25 oz. per sq.ft.

Unfabricated sample No. 115	0.24, 0.25, 0.24	2, 2, 2, 3, 3
	Avg. 0.25	

Coating thickness, in.: Min. 0.00025, Max. 0.00088
Wrap test performance, good
Iron content of coating, 8.3 per cent

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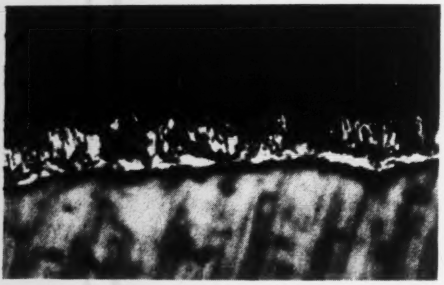
* See note at the end of Table I - K.

TABLE I - B.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 117; Gage, 6
Coating weight, 0.27 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 117	0.26, 0.27, 0.29	2, 2, 2
	Avg. 0.27	

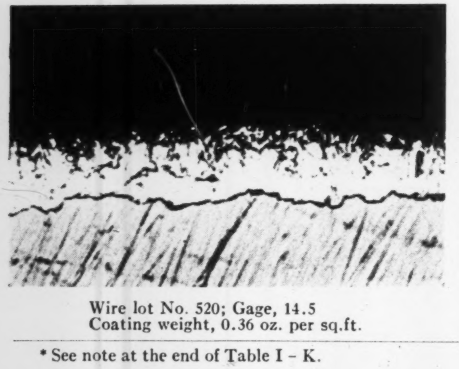
Coating thickness, in.: Min. 0.00025, Max. 0.00038
Wrap test performance, good
Iron content of coating, 6.0 per cent

* See note at the end of Table I - K.

TABLE I - C.—ZINC COATED SPECIMENS: 0.35 TO 0.45 OZ. PER SQ.FT. NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 520	280	18.7	61 500	62 900	0.27	0.28	0.09	7.3	0.13	0.42	0.059	0.025	0.04	0.23	0.02
No. 521	270	10.1	59 400	62 100	0.54	0.18	0.12	9.1	0.12	0.37	0.013	0.021	0.07	0.24	0.02
No. 522	500	1.5	107 400	112 300	0.25	0.01	0.09	7.5	0.09	0.44	0.014	0.024	0.13	0.23	0.03
No. 421	470	19.3	62 000	64 600	0.56	0.07	0.12	8.1	0.12	0.38	0.008	0.027	0.07	0.22	0.02
No. 422	500	15.8	64 700	66 500	0.29	0.11	0.09	6.9	0.12	0.42	0.053	0.024	0.02	0.24	0.02
No. 423	400	17.2	52 700	53 400	N.D.	N.D.	0.05	7.1	0.07	0.31	0.013	0.027	0.01	0.27	0.02
No. 282	1320	13.0	76 900	77 800	0.30	N.D.	0.07	7.2	0.10	0.46	0.016	0.024	0.14	0.25	0.02
No. C - 421: Barbed Wire: Coating, 0.37 oz. per sq.ft. Preece Dips* withstood: 4, 4, 4, 4									0.10	0.45	0.025	0.027	0.13	0.25	0.04

N.D. = not detected—that is, less than 0.01 per cent.



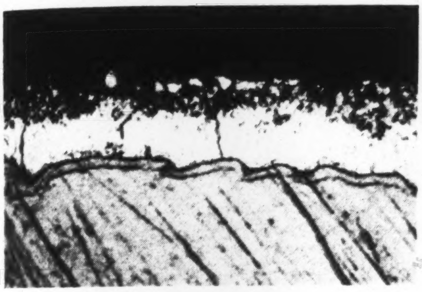
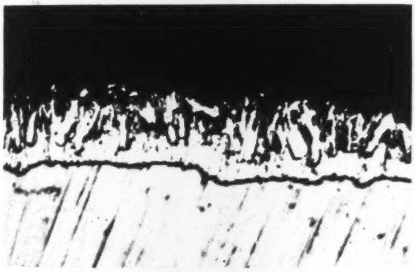
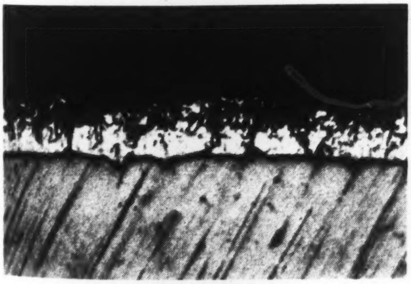
Wire lot No. 520; Gage, 14.5
Coating weight, 0.36 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 520 Interior of fence No. 520	0.33, 0.34, 0.34 0.38	3, 3, 3, 3, 3 4, 4, 4, 4, 4
	Avg. 0.36	

Coating thickness, in.: Min. 0.0005, Max. 0.00075
Wrap test performance, good
Iron content of coating, 7.3 per cent

* See note at the end of Table I - K.

TABLE I - C.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 521; Gage, 14.5 Coating weight, 0.38 oz. per sq.ft.	Unfabricated sample No. 521 Interior of fence No. 521	0.39, 0.41, 0.39 0.36	5, 5, 5, 5, 5 4, 4, 4, 4, 4
		Avg. 0.38	
	Coating thickness, in.: Min. 0.00075, Max. 0.00094 Wrap test performance, good Iron content of coating, 9.1 per cent		
 Wire lot No. 522; Gage, 14.5 Coating weight, 0.44 oz. per sq.ft.	Unfabricated sample No. 522 Interior of fence No. 522	0.45, 0.44 0.44	3, 3, 4, 4, 4 4, 4, 4, 4, 4
		Avg. 0.44	
	Coating thickness, in.: Min. 0.0005, Max. 0.001 Wrap test performance, good Iron content of coating, 7.5 per cent		
 Wire lot No. 421; Gage, 12.5 Coating weight, 0.47 oz. per sq.ft.	Unfabricated sample No. 421 Interior of fence No. 421 Barbed wire No. 422	0.47, 0.49, 0.51 0.49 0.44	3, 4, 4, 4, 4 5, 5, 5, 5 3, 3, 3
		Avg. 0.47	
	Coating thickness, in.: Min. 0.00019, Max. 0.00088 Wrap test performance, good Iron content of coating, 8.1 per cent		

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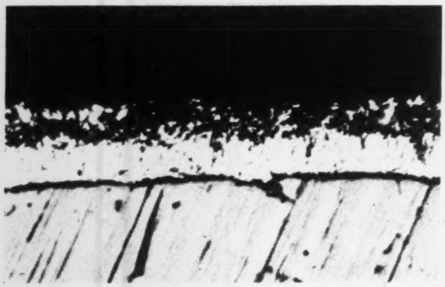
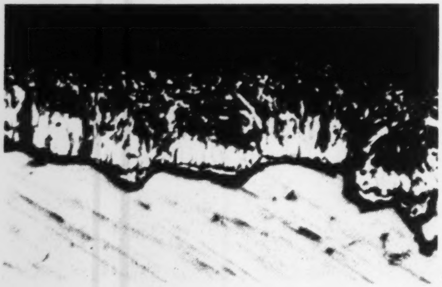
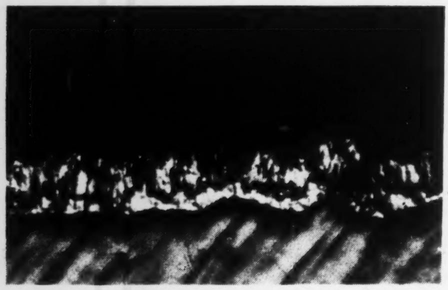
* See note at the end of Table I - K.

TABLE I - C.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 422; Gage, 12.5 Coating weight, 0.35 oz. per sq.ft.	Unfabricated sample No. 422 Interior of fence No. 422	0.39, 0.38 0.31, 0.31	3, 3, 3, 3, 3 3, 3, 3
		Avg. 0.35	
	Coating thickness, in.: Min. 0.00038, Max. 0.00088 Wrap test performance, peeled Iron content of coating, 6.9 per cent		
 Wire lot No. 423; Gage, 12.5 Coating weight, 0.31 oz. per sq.ft.	Unfabricated sample No. 423 Interior of fence No. 423 Barbed wire No. 420	0.36, 0.33, 0.36 0.31, 0.31 0.28	3, 3, 3, 3, 3 3, 3, 4 3, 3, 3
		Avg. 0.31	
	Coating thickness, in.: Min. 0.00044, Max. 0.001 Wrap test performance, good Iron content of coating, 7.1 per cent		
 Wire lot No. 282; Gage, 9 Coating weight, 0.37 oz. per sq.ft.	Unfabricated sample No. 282	0.37, 0.37, 0.38	4, 4, 4
		Avg. 0.37	
	Coating thickness, in.: Min. 0.00038, Max. 0.00088 Wrap test performance, good Iron content of coating, 7.2 per cent		

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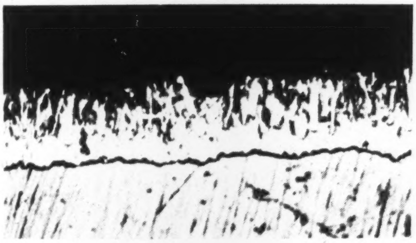
* See note at the end of Table I - K.

TABLE I - D.—ZINC COATED SPECIMENS: 0.45 TO 0.55 OZ. PER SQ.FT. NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 325	730	18.7	63 200	65 500	0.29	0 33	0.10	4.1	0.13	0.42	0.055	0.024	0.03	0.23	0.02
No. 326	700	15.8	59 500	60 600	N.D	N D.	0.03	8.5	0.08	0.39	0.017	0.037	0.10	0.06	0.03
No. 327	1160	7.0	101 000	104 700	0.13	0.11	0.09	8.1	0.10	0.44	0.017	0.026	0.13	0.24	0.03
No. 329	720	14.7	62 500	64 700	0.56	0.21	0.11	6.8	0.12	0.39	0.009	0.026	0.07	0.24	0.02
No. 225	1650	6.7	94 600	96 800	0.22	0.10	0.09	8.5	0.11	0.44	0.016	0.023	0.13	0.24	0.03
No. 226	1150	18.2	65 800	67 400	N.D.	N.D.	0.08	7.6	0.16	0.55	0.019	0.036	0.10	0.25	0.04
No. 227	1640	7.0	95 100	99 200	0.57	0.14	0.13	7.9	0.12	0.39	0.008	0.026	0.07	0.25	0.01
No. 228	1080	14.7	61 600	63 300	0.35	0.35	0.07	6.8	0.12	0.43	0.053	0.021	0.04	0.22	0.02
No. 125	1840	16.8	63 300	64 100	0.30	N.D.	0.14	6.5	0.12	0.38	0.007	0.024	0.09	0.23	0.02
No. 127	2540	7.5	86 800	88 600	0.34	0.07	0.05	7.6	0.12	0.67	0.007	0.024	0.01	0.05	0.01

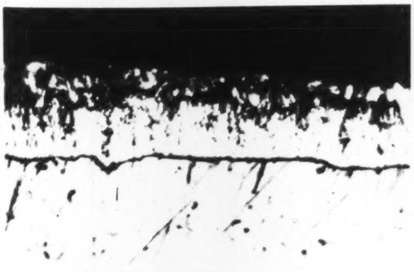
N.D. = not detected—that is, less than 0.01 per cent.



Wire lot No. 325; Gage, 11
Coating weight, 0.44 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 325	0.50, 0.50	5, 5, 5, 5
Interior of fence No. 325	0.52	5
Top of fence No. 520	0.37	4, 4, 4, 4, 4
Bottom of fence No. 520	0.39	4, 4, 4, 4, 4
	Avg. 0.44	

Coating thickness, in.: Min. 0.00081, Max. 0.00094
Wrap test performance, good
Iron content of coating, 4.1 per cent



Wire lot No. 326; Gage, 11
Coating weight, 0.38 oz. per sq.ft.

In Exposure Test as:	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 326	0.39, 0.40, 0.41	0, 2, 2, 2, 2
Interior of fence No. 326	0.35	3, 4, 4, 4, 4
	Avg. 0.38	

Coating thickness, in.: Min. 0.00038, Max. 0.00088
Wrap test performance, good
Iron content of coating, 8.5 per cent

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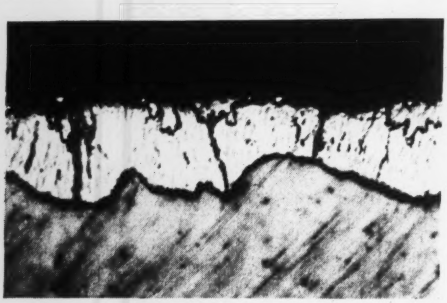
*See note at the end of Table I - K.

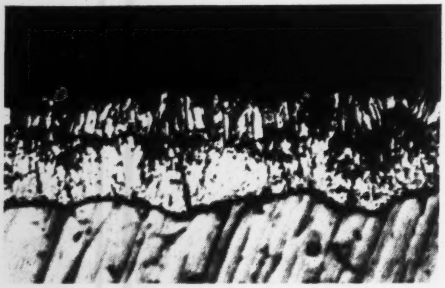
TABLE I - D.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 327; Gage, 11
Coating weight, 0.47 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 327	0.47, 0.48	4, 4, 4, 4
Interior of fence No. 327	0.44	5, 5, 5
Top of fence No. 522	0.48	4, 6, 6, 6, 6
Bottom of fence No. 522	0.48	6, 6, 6, 6, 6
	Avg. 0.47	

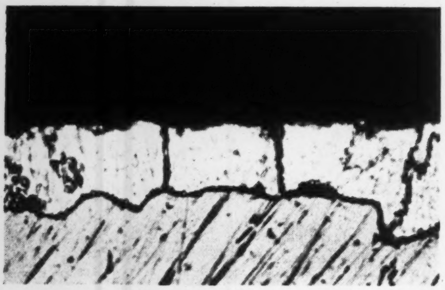
Coating thickness, in.: Min. 0.0005, Max. 0.00088
Wrap test performance, flaked
Iron content of coating, 8.1 per cent



Wire lot No. 329; Gage, 11
Coating weight, 0.54 oz. per sq.ft.

Unfabricated sample No. 329	0.55, 0.57	3, 4, 5, 5, 5
Top of fence No. 521	0.45	6, 6, 6, 6, 6
Bottom of fence No. 521	0.61, 0.64	6, 6, 6, 6, 6
	Avg. 0.54	

Coating thickness, in.: Min. 0.00088, Max. 0.001
Wrap test performance, flaked
Iron content of coating, 6.8 per cent



Wire lot No. 225; Gage, 9
Coating weight, 0.45 oz. per sq.ft.

Unfabricated sample No. 225	0.45, 0.45, 0.46	4, 5, 5, 5, 5
Interior of fence No. 225	—	4, 4, 4
Top of fence No. 225	0.49	4, 4, 4
Bottom of fence No. 225	0.44	5, 5, 5
Top of fence No. 327	0.43	5, 5, 5
Bottom of fence No. 327	0.47	5, 5, 5, 5
	Avg. 0.45	

Coating thickness, in.: Min. 0.00044, Max. 0.00081
Wrap test performance, flaked
Iron content of coating, 8.5 per cent

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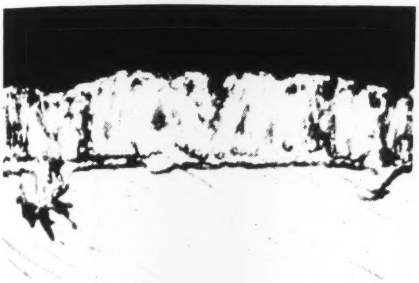
* See note at the end of Table I - K.

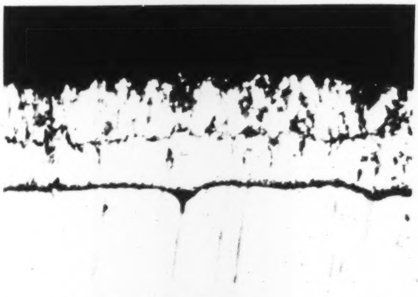
TABLE I - D.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 226; Gage, 9
Coating weight, 0.45 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 226	0.47, 0.46, 0.47	4, 4, 4, 4, 4
Top of fence No. 326	0.45	4, 4, 4, 4, 4
Bottom of fence No. 326	0.45	5, 4, 4, 4, 4
	Avg. 0.45	

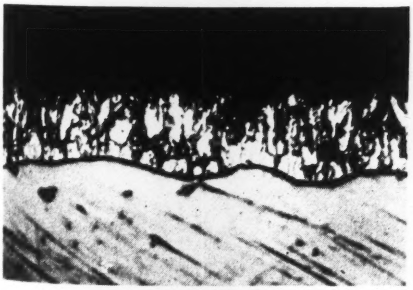
Coating thickness, in.: Min. 0.00038, Max. 0.00075
Wrap test performance, flaked
Iron content of coating, 7.6 per cent



Wire lot No. 227; Gage, 9
Coating weight, 0.52 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 227	0.61 0.58, 0.59, 0.59	6, 5, 6, 6, 6
Interior of fence No. 227	—	5, 5, 5
Top of fence No. 227	0.48	6, 6, 6
Bottom of fence No. 227	0.49	5, 5, 5
	Avg. 0.52	

Coating thickness, in.: Min. 0.001, Max. 0.0013
Wrap test performance, good
Iron content of coating, 7.9 per cent



Wire lot No. 228; Gage, 9
Coating weight, 0.50 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 228	0.48, 0.49, 0.50	3, 3, 3, 4, 4
Interior of fence No. 228	—	4, 4, 4
Top of fence No. 228	0.48	4, 4, 4
Bottom of fence No. 228	0.48	4, 4, 4
Top of fence No. 325	0.50	5, 5, 5, 5, 5
Bottom of fence No. 325	0.53	5, 5, 5, 5, 5
	Avg. 0.50	

Coating thickness, in.: Min. 0.00044, Max. 0.00088
Wrap test performance, good
Iron content of coating, 6.8 per cent

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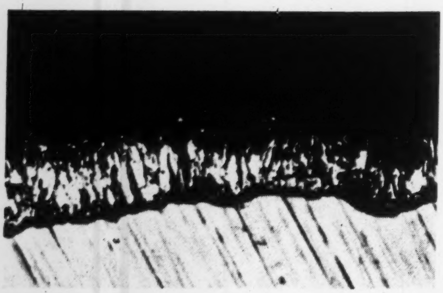
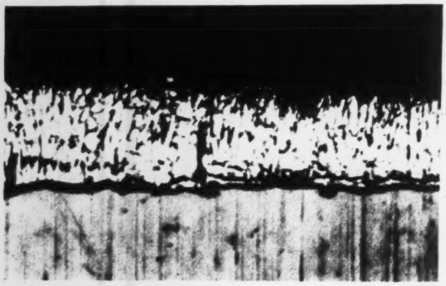
[*] See note at the end of Table I - K.

TABLE I - D.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 125; Gage, 6 Coating weight, 0.41 oz. per sq.ft.	Unfabricated sample No. 125	0.40, 0.41, 0.42 Avg. 0.41	4, 4, 4, 4, 4
	Coating thickness, in.: Min. 0.00025, Max. 0.00075 Wrap test performance, good Iron content of coating, 6.5 per cent		
 Wire lot No. 127; Gage, 6 Coating weight, 0.54 oz. per sq.ft.	Unfabricated sample No. 127	0.53, 0.55, 0.53 Avg. 0.54	5, 5, 5, 5, 5
	Coating thickness, in.: Min. 0.00063, Max. 0.00125 Wrap test performance, flaked Iron content of coating, 7.6 per cent		

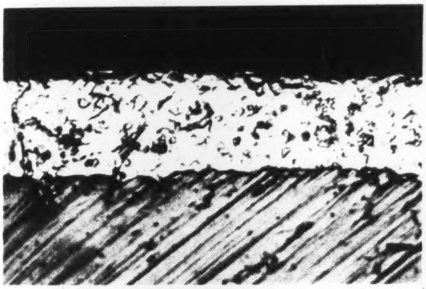
* See note at the end of Table I - K.

TABLE I - E.–ZINC COATED SPECIMENS: 0.50 TO 0.60 OZ. PER SQ.FT. NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 530	310	10.0	70 100	73 200	N.D.	N.D.	N.D.	0.07	0.05	0.34	0.013	0.030	0.008	0.28	0.03
No. 531	500	4.0	107 600	112 500	N.D.	N.D.	0.04	4.8	0.10	0.46	0.016	0.028	0.14	0.25	0.03
No. A - 532[a] (Fence sample) (Coating, 0.49 oz. per sq.ft.). (Preece dips* withstood, 5, 5, 5, 5, 5)					0.39	0.12	0.06	7.9	0.23	0.51	0.031	0.034	0.15	0.18	0.06
No. 430	780	6.5	104 000	108 300	0.43	0.15	0.13	8.7	0.13	0.39	0.008	0.028	0.07	0.27	0.02
No. 431	880	6.8	110 000	112 800	0.27	0.06	0.08	7.8	0.10	0.46	0.014	0.025	0.14	0.24	0.02
No. 432	510	9.2	68 000	70 800	N.D.	N.D.	0.007	0.14	0.05	0.29	0.010	0.023	0.003	0.27	00.2
No. A - 433[a] (Fence sample) (Coating, 0.49 oz. per sq.ft.). (Preece dips* withstood, 5, 5, 5)					0.25	0.11	0.09	8.1	0.19	0.48	0.013	0.033	0.12	0.17	0.04

N.D. = not detected—that is, less than 0.01 per cent.

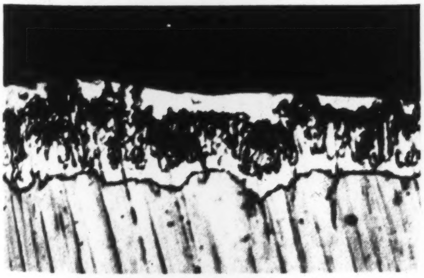
[a] These samples appear in exposure test only as farm field fences. Analyses on wire cut from interior of fences.



Wire lot No. 530; Gage, 14.5
Coating weight, 0.61 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 530 Interior of fence No. 530	0.58, 0.59 0.62 Avg. 0.61	3, 3, 3, 3, 3 4, 4, 4, 4, 4

Coating thickness, in.: Min. 0.00094, Max. 0.00106
Wrap test performance, peeled
Iron content of coating, 0.07 per cent



Wire lot No. 531; Gage, 14.5
Coating weight, 0.60 oz. per sq.ft.

In Exposure Test as:	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 531 Interior of fence No. 531	0.58, 0.58 0.61 Avg. 0.60	4, 4, 4, 3, 3 4, 4, 4, 4, 4

Coating thickness, in.: Min. 0.00069, Max. 0.00119
Wrap test performance, good
Iron content of coating, 4.8 per cent

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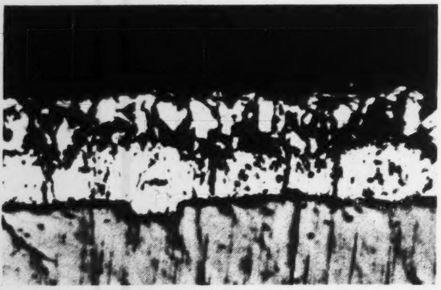
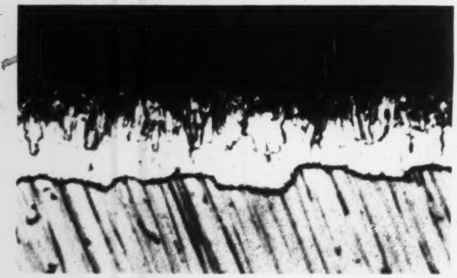
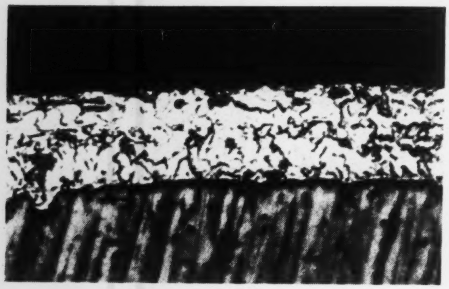
* See note at the end of Table I - K.

TABLE I - E.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 430; Gage, 12.5 Coating weight, 0.54 oz. per sq.ft.	Unfabricated sample No. 430	0.55, 0.57	5, 5, 5, 6, 6
	Interior of fence No. 430	0.52	6, 6, 6
	Barbed wire No. 431	0.53	2, 2, 2
		Avg. 0.54	
	Coating thickness, in.: Min. 0.00088, Max. 0.00094 Wrap test performance, flaked Iron content of coating, 8.7 per cent		
 Wire lot No. 431; Gage, 12.5 Coating weight, 0.48 oz. per sq.ft.	Unfabricated sample No. 431	0.48, 0.49, 0.49	5, 5, 5, 5, 5
	Interior of fence No. 431	0.48	5, 5, 5
	Barbed wire No. 430	0.45, 0.47	5, 5, 5
		Avg. 0.48	
	Coating thickness, in.: Min. 0.00063, Max. 0.00088 Wrap test performance, good Iron content of coating, 7.8 per cent		
 Wire lot No. 432; Gage, 12.5 Coating weight, 0.57 oz. per sq.ft.	Unfabricated sample No. 432	0.59, 0.58	3, 3, 3, 3, 3
	Interior of fence No. 432	0.60	3, 3, 3
	Barbed wire No. 432	0.53	4, 4, 5
		Avg. 0.57	
	Coating thickness, in.: Min. 0.00081, Max. 0.00094 Wrap test performance, good Iron content of coating, 0.14 per cent		

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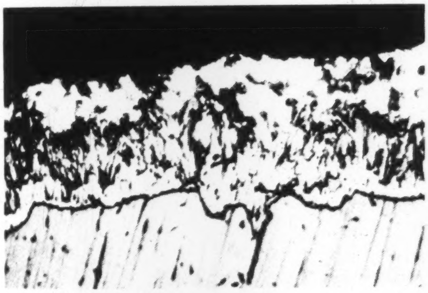
* See note at the end of Table I - K.

TABLE I - F.—ZINC COATED SPECIMENS: 0.60 TO 0.70 OZ. PER SQ.FT. NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 335...	1040	7.5	93 800	96 400	N.D.	N.D.	0.04	5.9	0.10	0.46	0.014	0.025	0.14	0.24	0.03
No. 336...	760	17.3	65 700	69 300	0.61	0.14	0.13	7.4	0.13	0.39	0.006	0.026	0.07	0.25	0.02
No. 337...	860	15.8	78 600	82 400	0.65[a]	0.16	0.07	6.2	0.27	0.46	0.019	0.036	0.19	0.21	0.04
No. 338...	1020	2.0	92 000	94 600	N.D.	N.D.	0.006	0.04	0.05	0.29	0.003	0.017	0.01	0.24	0.01
No. 235...	1680	7.5	97 600	101 700	0.13	N.D.	0.05	6.5	0.26	0.44	0.015	0.040	0.17	0.20	0.06
No. 236...	1270	6.0	74 700	77 000	N.D.	N.D.	N.D.	0.12	0.04	0.08	0.003	0.034	0.01	0.26	0.01
No. 237...	1540	6.7	91 000	94 900	N.D.	N.D.	0.04	5.0	0.09	0.46	0.014	0.034	0.14	0.25	0.03
No. 238...	1650	8.3	94 700	97 000	0.30	0.11	0.13	7.7	0.12	0.36	0.008	0.026	0.07	0.24	0.02
No. 239...	1120	17.7	63 400	66 000	0.30	0.32	0.11	6.7	0.13	0.43	0.054	0.023	0.03	0.23	0.03
No. 135...	2560	7.2	92 600	95 900	0.008	N.D.	0.04	5.5	0.11	0.44	0.014	0.024	0.14	0.22	0.03
No. 138...	1960	17.7	67 400	68 400	0.39	0.46	0.11	6.4	0.14	0.43	0.058	0.023	0.04	0.22	0.02
No. 139...	1920	14.2	64 700	66 000	0.86	0.17	0.12	7.2	0.12	0.37	0.007	0.025	0.08	0.24	0.02
No. A236 (Fence sample)...									0.05	0.15	0.003	0.037	<0.01	0.27	<0.01

N.D. = not detected—that is, less than 0.01 per cent.

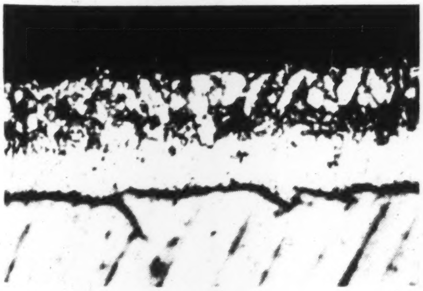
[a] Check analyses of lead content of coating, 0.70 per cent.



Wire lot No. 335; Gage, 11
Coating weight, 0.61 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 335	0.60, 0.61	3, 4, 4, 4
Interior of fence No. 335	0.63	4, 4, 4
Top of fence No. 531	0.59	4, 5, 5, 5, 5
Bottom of fence No. 531	0.60	4, 5, 5, 5, 5
	Avg. 0.61	

Coating thickness, in.: Min. 0.00063, Max. 0.00094
Wrap test performance, checks
Iron content of coating, 5.9 per cent



Wire lot No. 336; Gage, 11
Coating weight, 0.66 oz. per sq.ft.

In Exposure Test as:	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 336	0.72, 0.72, 0.73, 0.75	6, 7, 7, 7, 7
Interior of fence No. 336	0.60	7, 7, 7
	Avg. 0.66	

Coating thickness, in.: Min. 0.001, Max. 0.00119
Wrap test performance, good
Iron content of coating, 7.4 per cent

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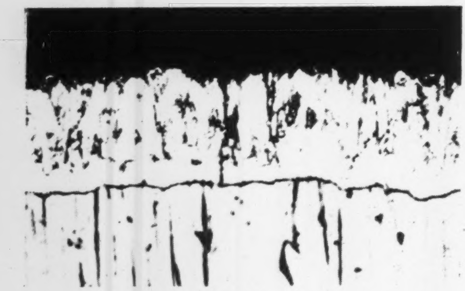
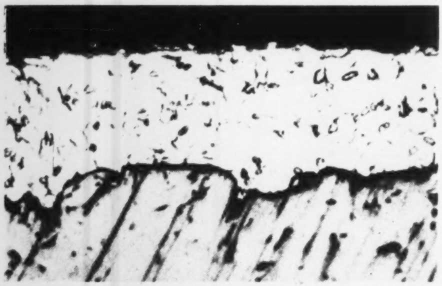
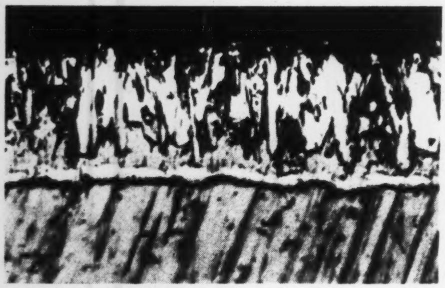
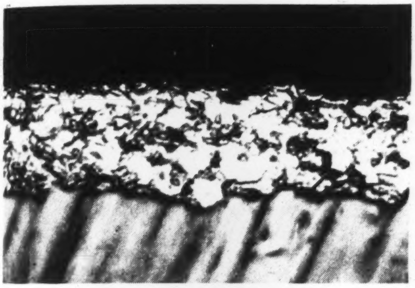
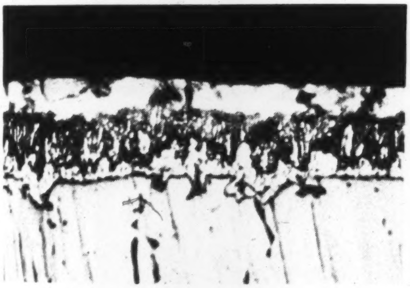
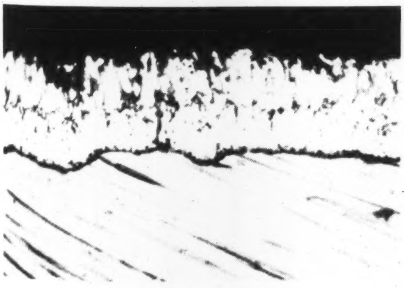
* See note at the end of Table I - K.

TABLE I - F.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 337; Gage, 11 Coating weight, 0.57 oz. per sq.ft	Unfabricated sample No. 337	0.67, 0.66	5, 5, 6, 6, 6
	Interior of fence No. 337	0.59	6, 6, 6
	Top of fence No. 532	0.50	6, 6, 6, 6, 6
	Bottom of fence No. 532	0.52	6, 6, 6, 6, 6
		Avg. 0.57	
	Coating thickness, in.: Min. 0.00088, Max. 0.00125 Wrap test performance, checks Iron content of coating, 6.2 per cent		
 Wire lot No. 338; Gage, 11 Coating weight, 0.69 oz. per sq.ft.	Unfabricated sample No. 338	0.66, 0.69	4, 4, 3, 3, 3
	Interior of fence No. 338	0.76	3, 4, 4
	Top of fence No. 530	0.67	4, 4, 4, 4, 4
	Bottom of fence No. 530	0.65	3, 3, 4, 4, 4
		Avg. 0.69	
	Coating thickness, in.: Min. 0.00113, Max. 0.00125 Wrap test performance, good Iron content of coating, 0.04 per cent		
 Wire lot No. 235; Gage, 9 Coating weight, 0.67 oz. per sq.ft.	Unfabricated sample No. 235	0.79, 0.82, 0.83 0.82	6, 6, 7, 7, 7
	Interior of fence No. 235	—	6, 6, 7
	Top of fence No. 235	0.60	6, 6, 6
	Bottom of fence No. 235	0.62	6, 6, 7
	Top of fence No. 337	0.68	6, 6, 6
	Bottom of fence No. 337	0.64	6, 7, 7
		Avg. 0.67	
	Coating thickness, in.: Min. 0.00125, Max. 0.0015 Wrap test performance, good Iron content of coating, 6.5 per cent		

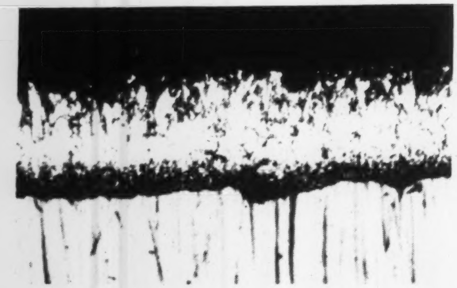
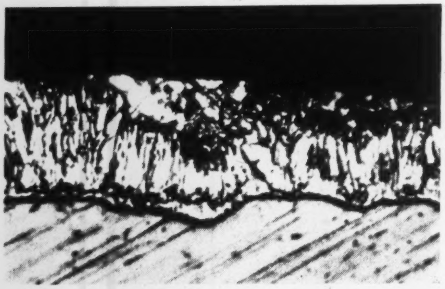
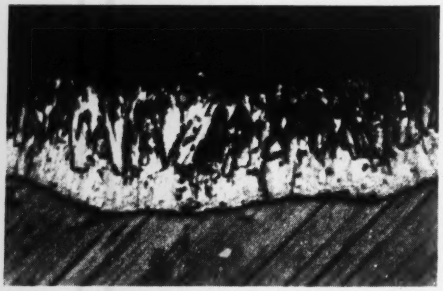
* See note at the end of Table I - K.

TABLE I - F.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 236; Gage, 9 Coating weight, 0.68 oz. per sq.ft.	Unfabricated sample No. 236	0.66, 0.66	4, 4, 4, 4, 4
	Interior of fence No. 236	—	4, 4, 4, 4, 4
	Top of fence No. 236	0.68	4, 4, 4, 4, 4
	Bottom of fence No. 236	0.73	4, 4, 4, 4, 4
	Top of fence No. 338	0.69	3, 4, 4
	Bottom of fence No. 338	0.65	3, 3, 4
		Avg. 0.68	
	Coating thickness, in.: Min. 0.00113, Max. 0.00131 Wrap test performance, good Iron content of coating, 0.12 per cent		
 Wire lot No. 237; Gage, 9 Coating weight, 0.63 oz. per sq.ft.	Unfabricated sample No. 237	0.71, 0.72, 0.74	5, 5, 5, 5, 5
	Interior of fence No. 237	—	4, 4, 4
	Top of fence No. 237	0.67	5, 5, 5
	Bottom of fence No. 237	0.55	4, 4, 4
	Top of fence No. 335	0.58	3, 3, 4
	Bottom of fence No. 335	0.61	4, 4, 4
		Avg. 0.63	
	Coating thickness, in.: Min. 0.00075, Max. 0.001 Wrap test performance, good Iron content of coating, 5.0 per cent		
 Wire lot No. 238; Gage, 9 Coating weight, 0.60 oz. per sq.ft.	Unfabricated sample No. 238	0.59, 0.60, 0.61	6, 6, 6, 6, 6
	Interior fence No. 238	—	7, 7, 8
	Top of fence No. 238	0.59	7, 7, 8
	Bottom of fence No. 238	0.61	7, 7, 7
	Top of fence No. 336	0.59	7, 7, 7
	Bottom of fence No. 336	0.61	7, 7, 7
		Avg. 0.60	
	Coating thickness, in.: Min. 0.00075, Max. 0.001 Wrap test performance, good Iron content of coating, 7.7 per cent		

* See note at the end of Table I - K.

TABLE I-F.—ZINC COATED SPECIMENS.—*Cont.*

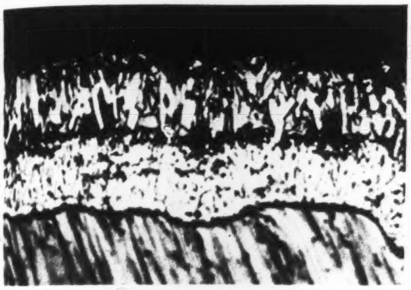
	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 239; Gage, 9 Coating weight, 0.65 oz. per sq.ft.	Unfabricated sample No. 239	0.65, 0.66 Avg. 0.65	5, 5, 5, 5
	Coating thickness, in.: Min. 0.00106, Max. 0.00125 Wrap test performance, good Iron content of coating, 6.7 per cent		
 Wire lot No. 135; Gage, 6 Coating weight, 0.74 oz. per sq.ft.	Unfabricated sample No. 135	0.73, 0.74, 0.75 Avg. 0.74	5, 5, 6, 6, 6
	Coating thickness, in.: Min. 0.001, Max. 0.00113 Wrap test performance, good Iron content of coating, 5.5 per cent		
 Wire lot No. 138; Gage, 6 Coating weight, 0.67 oz. per sq.ft.	Unfabricated sample No. 138	0.66, 0.66, 0.67 Avg. 0.67	7, 7, 7, 7
	Coating thickness, in.: Min. 0.001, Max. 0.00125 Wrap test performance, good Iron content of coating, 6.4 per cent		

* See note at the end of Table I-K.

TABLE I - F.—ZINC COATED SPECIMENS.—*Cont.*

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 139	0.61, 0.62 0.65, 0.67	6, 6, 6, 7, 7
	Avg. 0.64	

Coating thickness, in.: Min. 0.0005, Max. 0.002
Wrap test performance, good
Iron content of coating, 7.2 per cent



Wire lot No. 139; Gage, 6
Coating weight, 0.64 oz. per sq.ft.

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* See note at the end of Table I - K.

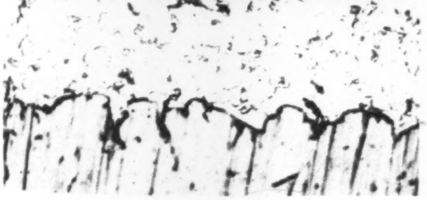
TABLE I - G.—ZINC COATED SPECIMENS: 0.70 TO 0.85 OZ. PER SQ.FT. NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 540	300	10.2	68 200	73 200	N.D.	N.D.	0.01	0.12	0.05	0.33	0.011	0.028	0.007	0.26	0.02
No. 541	350	15.0	76 100	79 500	0.12	N.D.	0.05	6.6	0.27	0.47	0.016	0.040	0.18	0.20	0.05
No. 542	510	3.5	106 200	115 900	N.D.	N.D.	0.04	6.4	0.11	0.45	0.017	0.026	0.13	0.24	0.05
No. 543	300	14.2	67 500	70 600	0.18	N.D.	0.05	3.3	0.12	0.46	0.019	0.038	0.17	0.23	0.03
No. 440	590	14.8	76 200	81 500	0.15	N.D.	0.05	6.7	0.25	0.45	0.015	0.038	0.17	0.23	0.05
No. 441	520	17.8	67 500	70 300	0.18	N.D.	0.04	3.8	0.13	0.46	0.017	0.034	0.18	0.22	0.02
No. 442	470	13.3	62 200	64 800	N.D.	N.D.	0.007	0.10	0.03	0.25	0.012	0.036	0.005	0.24	0.01
No. 443	750	6.2	99 600	102 800	N.D.	N.D.	0.04	5.5	0.09	0.46	0.015	0.025	0.14	0.26	0.03
No. 444	570	15.0	73 300	79 400	0.13	N.D.	0.04	6.4	0.24	0.43	0.014	0.037	0.17	0.23	0.05
No. 495—Made from wire lot No. 443. Chromated after zinc coating.															

N.D. = not detected—that is, less than 0.01 per cent.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 540 Interior of fence No. 540	0.72, 0.72 0.68	3, 4, 4, 4, 4 4, 4, 4, 4, 4
	Avg. 0.70	

Coating thickness, in.: Min. 0.00088, Max. 0.00119
Wrap test performance, good
Iron content of coating, 0.12 per cent



Wire lot No. 540; Gage, 14.5
Coating weight, 0.70 oz. per sq.ft.

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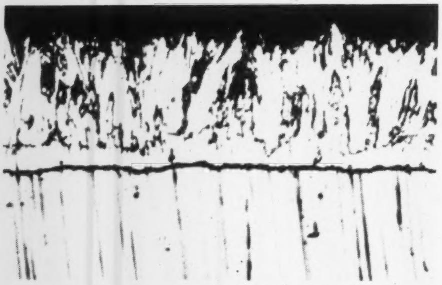
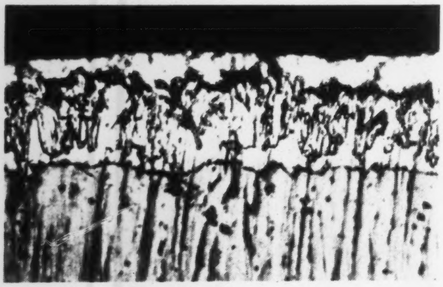
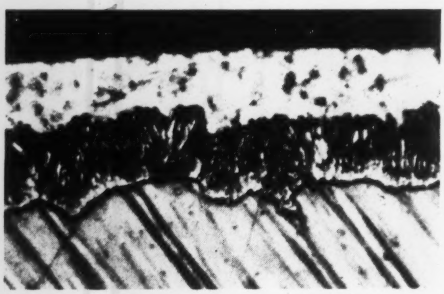
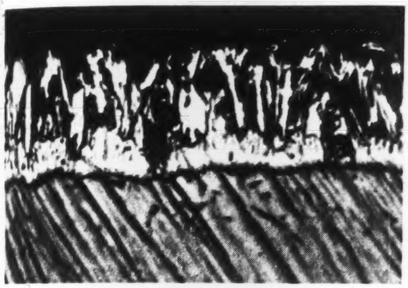
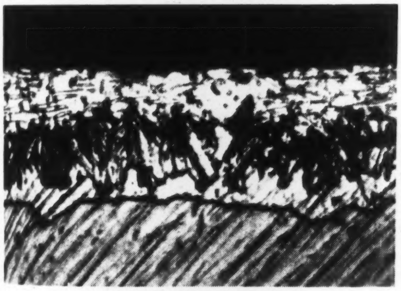
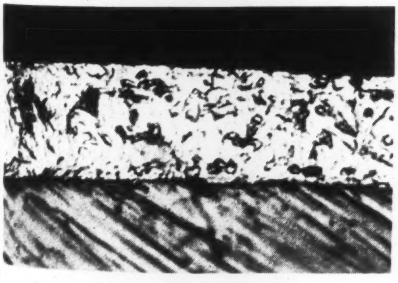
* See note at the end of Table I - K.

TABLE I - G.—ZINC COATED SPECIMENS.—*Cont.*

<table>
<tr><th rowspan="2"></th><th rowspan="2">In Exposure Test as:</th><th colspan="2">Determinations</th></tr>
<tr><th>Coating Weights</th><th>Preece Dips* Withstood</th></tr>
<tr><td rowspan="2">
Wire lot No. 541; Gage, 14.5
Coating weight, 0.76 oz. per sq.ft.</td><td>Unfabricated sample No. 541
Interior of fence No. 541</td><td>0.77, 0.80, 0.81
0.68, 0.72
Avg. 0.76</td><td>6, 6, 6, 6, 6
4, 4, 4, 4, 4</td></tr>
<tr><td colspan="3">Coating thickness, in.: Min. 0.00088, Max. 0.0015
Wrap test performance, good
Iron content of coating, 6.6 per cent</td></tr>
<tr><td rowspan="2">
Wire lot No. 542; Gage, 14.5
Coating weight, 0.70 oz. per sq.ft.</td><td>Unfabricated sample No. 542
Interior of fence No. 542</td><td>0.68, 0.69, 0.69
0.71
Avg. 0.70</td><td>4, 4, 4, 4, 4
5, 5, 5, 5, 5</td></tr>
<tr><td colspan="3">Coating thickness, in.: Min. 0.00113, Max. 0.0015
Wrap test performance, good
Iron content of coating, 6.4 per cent</td></tr>
<tr><td rowspan="2">
Wire lot No. 543; Gage, 14.5
Coating weight, 0.79 oz. per sq.ft.</td><td>Unfabricated sample No. 543
Interior of fence No. 543</td><td>0.82, 0.85, 0.85
0.74
Avg. 0.79</td><td>5, 5, 5, 5, 5
5, 5, 5, 5, 5</td></tr>
<tr><td colspan="3">Coating thickness, in.: Min. 0.00088, Max. 0.00175
Wrap test performance, peeled
Iron content of coating, 3.3 per cent</td></tr>
</table>

* See note at the end of Table I - K.

TABLE I - G.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 440; Gage, 12.5 Coating weight, 0.76 oz. per sq.ft.	Unfabricated sample No. 440	0.71 0.71, 0.72, 0.73	7, 7, 7, 7,7
	Interior of fence No. 440	0.79	3, 4, 4
		Avg. 0.76	
	Coating thickness, in.: Min. 0.00106, Max. 0.00138 Wrap test performance, flaked Iron content of coating, 6.7 per cent		
 Wire lot No. 441; Gage, 12.5 Coating weight, 0.78 oz. per sq.ft.	Unfabricated sample No. 441	0.75, 0.77, 0.80	3, 3, 5, 5, 5
	Interior of fence No. 441	0.76	5, 5, 5
	Barbed wire No. 442	0.82	5, 5, 5, 5, 5
		Avg. 0.78	
	Coating thickness, in.: Min. 0.00125, Max. 0.00138 Wrap test performance, good Iron content of coating, 3.8 per cent		
 Wire lot No. 442; Gage, 12.5 Coating weight, 0.72 oz. per sq.ft.	Unfabricated sample No. 442	0.66 0.65, 0.65, 0.66	3, 3, 3, 3, 3
	Interior of fence No. 442	0.86	4, 3, 3
	Barbed wire No. 441	0.64, 0.64	3, 3, 3
		Avg. 0.72	
	Coating thickness, in.: Min. 0.001, Max. 0.00113 Wrap test performance, good Iron content of coating, 0.10 per cent		

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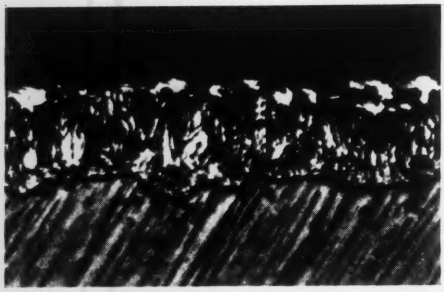
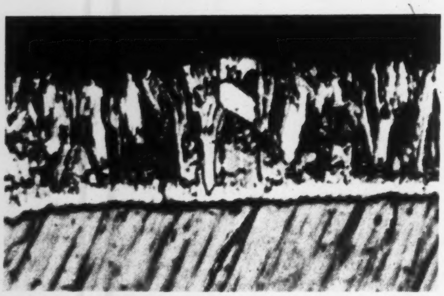
* See note at the end of Table I - K.

TABLE I - G.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations:	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 443; Gage, 12.5 Coating weight, 0.74 oz. per sq.ft.	Unfabricated sample No. 443 Interior of fence No. 443 Barbed wire No. 443	0.73, 0.75 0.78 0.67, 0.73	5, 5, 5, 6, 6 4, 4, 4, 4, 4 4, 4, 4
		Avg. 0.74	
	Coating thickness, in.: Min. 0.00094, Max. 0.00119 Wrap test performance, good Iron content of coating, 5.5 per cent		
 Wire lot No. 444; Gage, 12.5 Coating weight, 0.87 oz. per sq.ft.	Unfabricated sample No. 444	0.87, 0.87, 0.89	6, 6, 7, 7, 7
		Avg. 0.87	
	Coating thickness, in.: Min. 0.00125, Max. 0.00138 Wrap test performance, checks Iron content of coating, 6.4 per cent		

* See note at end of Table I - K.

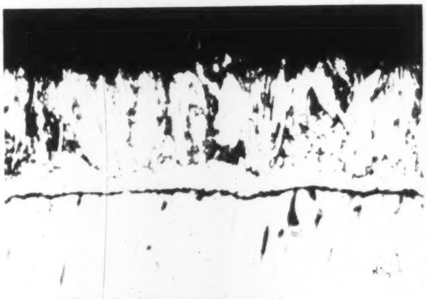
TABLE I - H.—ZINC COATED SPECIMENS: 0.80 TO 1.00 OZ. PER SQ.FT. NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 345	890	14.2	79 900	85 300	0.14	N.D.	0.05	6.9	0.25	0.46	0.018	0.035	0.19	0.20	0.05
No. 346	1070	8.5	94 500	100 800	N.D.	N.D.	0.04	5.2	0.10	0.44	0.019	0.027	0.14	0.25	0.03
No. 347	860	6.0	73 700	77 800	0.20	N.D.	0.005	3.8	0.13	0.46	0.020	0.038	0.17	0.23	0.03
No. 348	980	2.5	88 100	94 100	N.D.	N.D.	0.006	0.04	0.04	0.28	0.008	0.015	0.01	0.24	0.02
No. 245	1570	7.3	90 900	94 700	N.D.	N.D.	0.04	5.4	0.10	0.44	0.014	0.026	0.14	0.24	0.02
No. 246	1190	14.2	69 000	71 900	0.24	N.D.	0.04	3.7	0.12	0.46	0.015	0.033	0.18	0.22	0.02
No. 247	1790	7.7	102 700	107 000	0.09	N.D.	0.04	6.2	0.25	0.47	0.016	0.034	0.20	0.20	0.04
No. 248	1450	3.0	85 400	88 000	N.D.	N.D.	0.004	0.09	0.05	0.08	0.004	0.037	0.006	0.26	0.01
No. 148	2550	7.7	88 000	90 900	N.D.	N.D.	0.05	6.8	0.11	0.44	0.015	0.026	0.13	0.23	0.03
No. 149	1910	16.7	66 800	69 700	0.23	N.D.	0.05	6.4[a]	0.10	0.43	0.080	0.036	0.01	0.24	0.04
No. 296—Made from wire lot No. 245. Chromated after zinc coating.															
No. A248 (Fence sample)									0.05	0.15	0.011	0.029	<0.01	0.28	<0.01
BARBED WIRE SPECIMENS															
	Zinc Coat, oz. per sq.ft.		Preece Dips* Withstood												
No. C - 445	0.97		5, 6, 6		0.03	N.D.	0.02	3.9	0.13	0.40	0.059	0.036	0.13	0.24	0.04
No. C - 446	0.92		5, 5, 5		N.D.	N.D.	0.04	4.1	0.11	0.44	0.024	0.027	0.12	0.25	0.04

[a] Check analyses of iron content, 3.8 per cent.
N. D. = not detected—that is, less than 0.01 per cent.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 345	0.83, 0.83	7, 7, 7, 7, 7
Interior of fence No. 345	0.97	9, 9, 9
Top of fence No. 541	0.76	4, 4, 4, 4, 4
Bottom of fence No. 541	0.79	3, 4, 4, 4, 4
	Avg. 0.84	

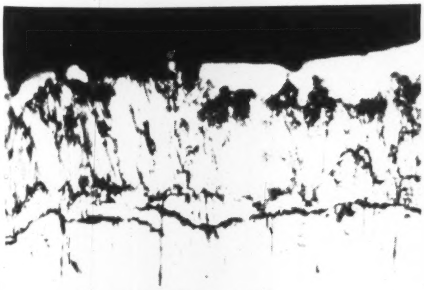
Coating thickness, in.: Min. 0.00138, Max. 0.0015
Wrap test performance, good
Iron content of coating, 6.9 per cent



Wire lot No. 345; Gage, 11
Coating weight, 0.84 oz. per sq.ft.

In Exposure Test as:	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 346	0.85, 0.84	5, 5, 6, 6, 5
Interior of fence No. 346	0.84	5, 5, 5
Top of fence No. 542	0.96, 0.96	7, 7, 7, 7, 7
Bottom of fence No. 542	0.88	6, 6, 7, 7, 7
	Avg. 0.88	

Coating thickness, in.: Min. 0.00106, Max. 0.0015
Wrap test performance, good
Iron content of coating, 5.2 per cent



Wire lot No. 346; Gage, 11
Coating weight, 0.88 oz. per sq.ft.

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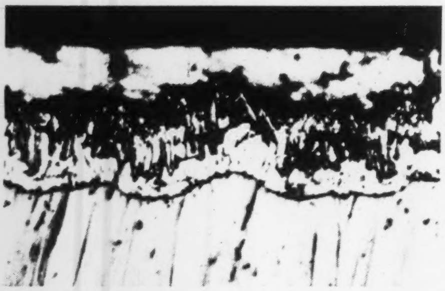
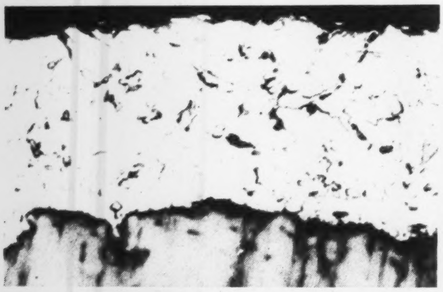
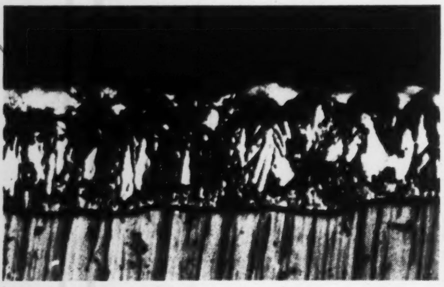
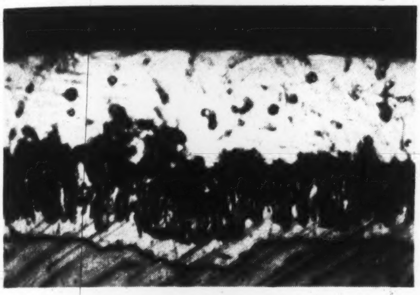
*See note at the end of Table I - K.

TABLE I - H.—ZINC COATED SPECIMENS.—*Cont.*

	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 347; Gage, 11 Coating weight, 0.88 oz. per sq.ft.	Unfabricated sample No. 347	0.95, 0.97	5, 6, 6, 6, 7
	Interior of fence No. 347	1.00	6, 7, 7
	Top of fence No. 543	0.78	6, 6, 6, 6, 6
	Bottom of fence No. 543	0.79	6, 6, 6, 6, 6
		Avg. 0.88	
	Coating thickness, in.: Min. 0.00113, Max. 0.00163 Wrap test performance, checks Iron content of coating, 3.8 per cent		
 Wire lot No. 348; Gage, 11 Coating weight, 1.05 oz. per sq.ft	Unfabricated sample No. 348	1.05, 1.05 1.02, 1.04, 1.05	6, 6, 6, 5, 5
	Interior of fence No. 348	1.07	6, 6, 6, 6, 6
	Top of fence No. 540	1.05	5, 5, 5, 5, 5
	Bottom of fence No. 540	1.06	5, 5, 5, 5, 5
		Avg. 1.05	
	Coating thickness, in.: Min. 0.00138, Max. 0.00175 Wrap test performance, flaked Iron content of coating, 0.04 per cent		
 Wire lot No. 245; Gage, 9 Coating weight, 0.81 oz. per sq.ft.	Unfabricated sample No. 245	0.80, 0.79	4, 4, 6, 4, 4
	Interior of fence No. 245	—	5, 6, 6
	Top of fence No. 245	0.83	5, 6, 6
	Bottom of fence No. 245	0.78	5, 6, 6
	Top of fence No. 346	0.81	5, 5, 5
	Bottom of fence No. 346	0.81	5, 5, 6
		Avg. 0.81	
	Coating thickness, in.: Min. 0.001, Max. 0.0015 Wrap test performance, good Iron content of coating, 5.4 per cent		

* See note at the end of Table I - K.

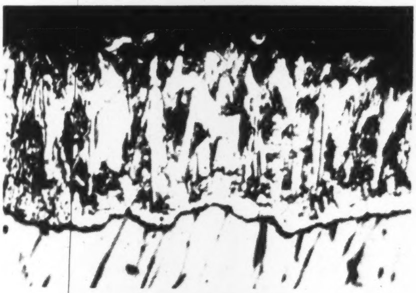
TABLE I - H.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 246; Gage, 9
Coating weight, 0.95 oz. per sq.ft.

In Exposure Test as:	Determinations	
	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 246	0.97, 0.97	5, 6, 6, 6
Interior of fence No. 246	—	5, 5, 5
Top of fence No. 246	0.94	5, 5, 6
Bottom of fence No. 246	0.98	5, 6, 5
Top of fence No. 347	0.89	6, 6, 6
Bottom of fence No. 347	0.95	6, 6, 6
	Avg. 0.95	

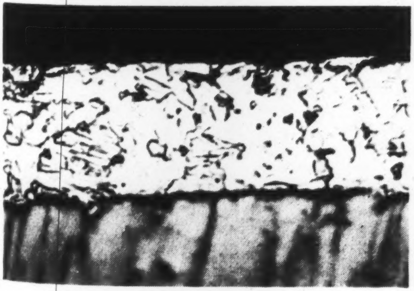
Coating thickness, in.: Min. 0.00075, Max. 0.00163
Wrap test performance, cracked
Iron content of coating, 3.7 per cent



Wire lot No. 247; Gage, 9
Coating weight, 0.96 oz. per sq.ft.

In Exposure Test as:	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 247	0.93, 0.93, 0.94, 0.98	8, 8, 8, 8, 8
Interior of fence No. 247	—	8, 9, 9,
Top of fence No. 247	0.95	8, 8, 8
Bottom of fence No. 247	1.00	9, 9, 9
Top of fence No. 345	1.01	9, 9, 9
Bottom of fence No. 345	0.91	7, 8, 8
	Avg. 0.96	

Coating thickness, in.: Min. 0.0015, Max. 0.0019
Wrap test performance, cracked
Iron content of coating, 6.2 per cent



Wire lot No. 248; Gage, 9
Coating weight, 0.81 oz. per sq.ft.

In Exposure Test as:	Coating Weights	Preece Dips* Withstood
Unfabricated sample No. 248	0.66, 0.66, 0.66	4, 4, 4, 4
Interior of fence No. 248	—	4, 4, 4, 4, 4
Top of fence No. 248	0.92	4, 4, 4, 4, 4
Bottom of fence No. 248	0.68	3, 3, 3, 4, 4
Top of fence No. 348	0.91	5, 5, 5, 5, 5
Bottom of fence No. 348	0.89	5, 5, 5, 5, 5
	Avg. 0.81	

Coating thickness, in.: Min. 0.001, Max. 0.00118
Wrap test performance, good
Iron content of coating, 0.09 per cent

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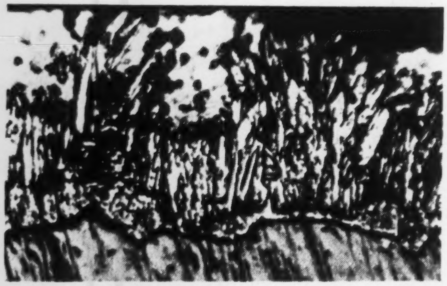
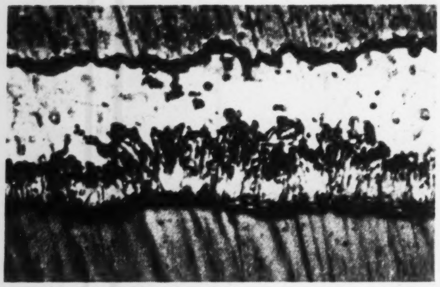
*See note at the end of Table I - K.

TABLE I - H.—ZINC COATED SPECIMENS.—*Cont.*

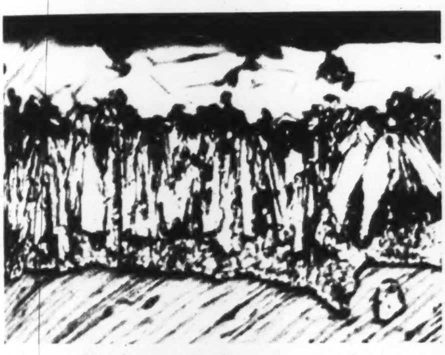
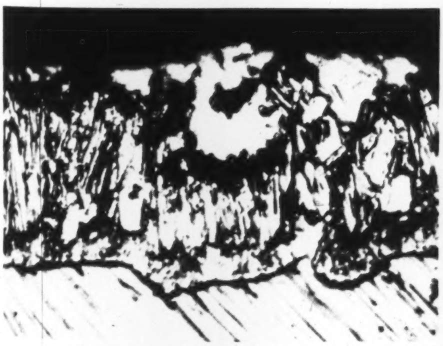
	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot No. 148; Gage, 6 Coating weight, 0.90 oz. per sq.ft.	Unfabricated sample No. 148 Coating thickness, in.: Min. 0.00113, Max. 0.00188 Wrap test performance, flaked Iron content of coating, 6.8 per cent	0.88, 0.90, 0.90 0.97 Avg. 0.90	6, 6, 6, 6, 6
 Wire lot No. 149; Gage, 6 Coating weight, 0.85 oz. per sq.ft.	Unfabricated sample No. 149 Coating thickness, in.: Min. 0.00075, Max. 0.00225 Wrap test performance, cracked Iron content of coating, 6.4 per cent Check analyses, 3.8 per cent	0.85, 0.85 Avg. 0.85	5, 5, 5, 5, 5

* See note at the end of Table I - K.

TABLE I - I.—ZINC COATED SPECIMENS: 1.20 TO 1.50 OZ. PER SQ.FT. NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 800....	2670	9.2	90 200	96 000	N.D.	N.D.	0.04	4.6	0.11	0.45	0.015	0.025	0.14	0.25	0.03
No. 801....	1820	2.2	105 500	111 400	N.D.	N.D.	0.04	4.7	0.10	0.45	0.014	0.024	0.14	0.24	0.03

N.D. = not detected—that is, less than 0.01 per cent.

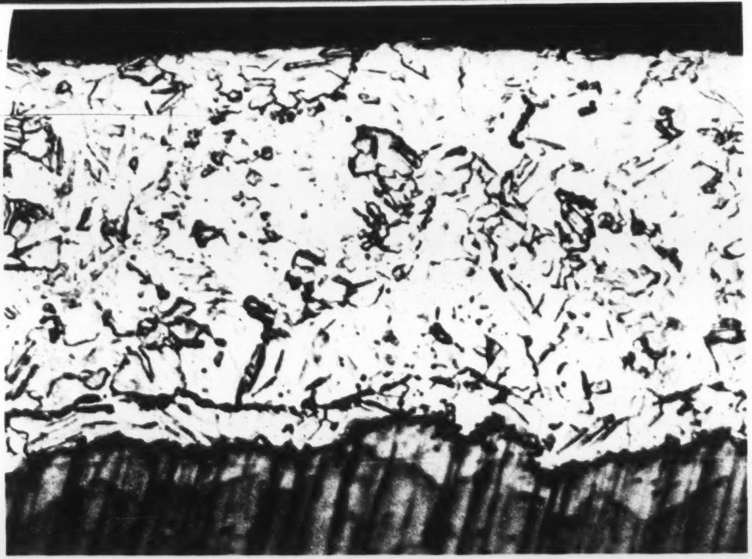
	In Exposure Test as:	Determinations	
		Coating Weights	Preece Dips* Withstood
 Wire lot no. 800; Gage, 6 Coating weight, 1.35 oz. per sq.ft.	Unfabricated sample No. 800	1.36, 1.35, 1.37, 1.38 Avg. 1.35	9, 9, 9
	Coating thickness, in.: Min. 0.00169, Max. 0.0025 Wrap test performance, cracked Iron content of coating, 4.6 per cent		
 Wire lot No. 801; Gage, 9 Coating weight, 1.20 oz. per sq.ft.	Unfabricated sample No. 801	1.20 Avg. 1.20	6, 7, 7, 7, 7
	Coating thickness, in.: Min. 0.00175, Max. 0.00213 Wrap test performance, checks Iron content of coating, 4.7 per cent		

* See note at the end of Table I - K.

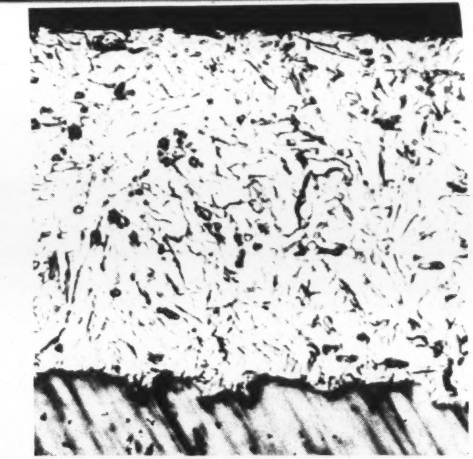
TABLE I - J.—ZINC COATED SPECIMENS: 1.60 TO 1.80 OZ. PER SQ.FT. NOMINAL COATING.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 551.....	540	1.0	121 100	139 800	N.D.	N.D.	0.08	0.09	0.14	0.39	0.014	0.024	0.12	0.21	0.03
No. 552.....	310	8.0	70 600	85 600	N.D.	N.D.	N.D.	0.04	0.06	0.35	0.009	0.024	0.008	0.20	0.01
No. 450.....	820	1.0	109 300	118 800	N.D.	N.D.	0.02	1.40	0.09	0.45	0.015	0.025	0.12	0.23	0.03
No. 451.....	510	7.8	69 100	78 700	0.003	N.D.	0.006	0.04	0.05	0.35	0.014	0.032	0.007	0.28	0.02
No. 350.....	640	14.8	58 400	65 000	N.D.	N.D.	0.001	0.02	0.08	0.39	0.006	0.020	0.01	0.20	0.02
No. 351.....	970	12.0	82 100	89 600	0.24	N.D.	0.04	0.60	0.27	0.47	0.017	0.035	0.20	0.21	0.05
No. 352	1340	1.5	118 400	131 200	N.D.	N.D.	0.02	1.40	0.09	0.44	0.014	0.025	0.14	0.24	0.02
No. 250	1380	10.3	77 400	83 900	0.27	N.D.	0.04	0.55	0.24	0.46	0.016	0.036	0.17	0.20	0.04
No. 251.....	1940	2.0	112 700	120 400	N.D.	N.D.	0.01	1.60	0.10	0.45	0.016	0.025	0.12	0.24	0.03
No. 252.....	1150	10.8	66 700	72 100	N.D.	N.D.	0.005	0.07	0.04	0.32	0.014	0.033	0.01	0.29	0.02
No. 151.....	3100	2.5	107 000	112 700	N.D.	N.D.	N.D.	1.50	0.10	0.43	0.011	0.029	0.11	0.25	0.02
BARBED WIRE SPECIMENS															
	Zinc Coat, oz. per sq.ft.		Preece Dips* Withstood												
No. C - 447.	1.96, 2.01, 1.99		8, 8, 8		N.D.	N.D.	N.D.	0.002	0.05	0.28	0.017	0.021	0.006	0.28	0.03
No. C - 494.	1.99, 1.99		8, 8, 8		N.D.	N.D.	N.D.	0.006	0.15	0.49	0.030	0.035	0.13	0.29	0.05
No. C - 450. (Galvanized after fabrication)	1.64		5, 5, 5, 5		Analysis not made										

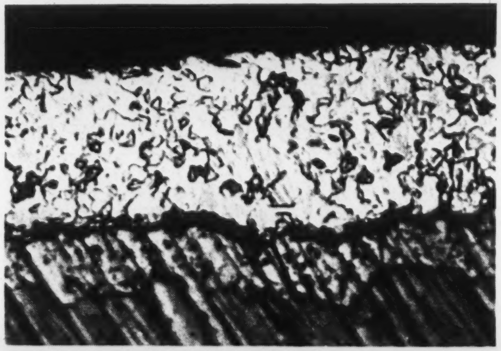
N.D. = not detected—that is, less than 0.01 per cent.



Wire lot No. 551; Gage, 14.5
Coating weight (avg.), 1.69 oz. per sq.ft.
In exposure test as unfabricated sample No. 551



Wire lot No. 552; Gage, 14.5
Coating weight (avg.), 2.08 oz. per sq.ft.
In exposure test as unfabricated sample No. 552



Wire lot No. 450; Gage, 12.5
Coating weight (avg.): 1.50 oz. per sq.ft.
In exposure test as Unfabricated sample No. 450
Barbed wire No. 452

	Wire Lot No. 551	Wire Lot No. 552	Wire Lot No. 450
Coating weight tests:			
Unfabricated wire	1.67, 1.70	2.07, 2.08, 2.10	1.24, 1.38 1.48, 1.56
Barbed wire	....	....	1.50, 1.53
Preece dips withstood:*			
Unfabricated wire	7, 7, 7, 8, 8	7, 7, 7, 7, 8	5, 5, 5, 6, 6
Barbed wire	....	....	8, 8, 8
Coating thickness, in.	Min. 0.001 Max. 0.0045	Min. 0.00344 Max. 0.0035	Min. 0.00075 Max. 0.003
Wrap test performance	Good	Flaked	Good
Iron content of coating, per cent	0.09	0.04	1.4

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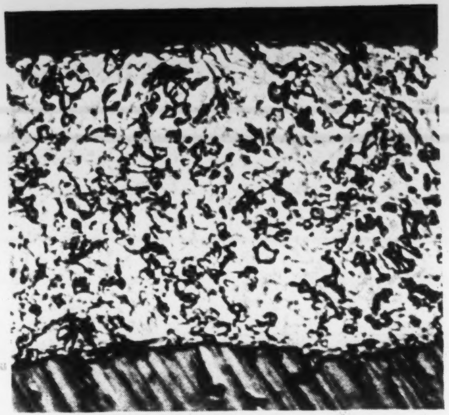
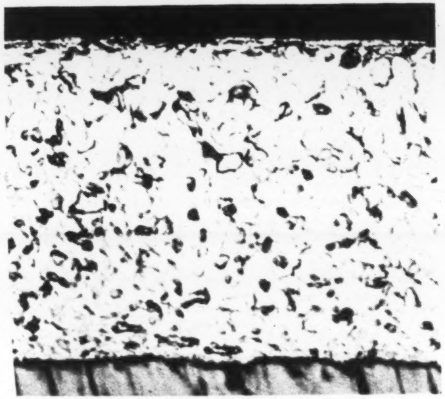
* See note at the end of Table I - K.

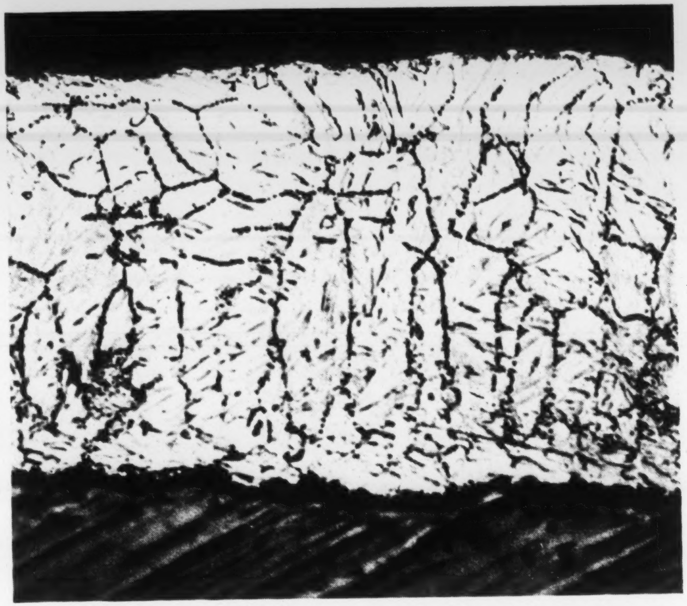
TABLE I - J.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 451; Gage, 12.5
Coating weight (avg.), 1.83 oz. per sq.ft.
In exposure test as {Unfabricated sample No. 451
Barbed wire No. 451}



Wire lot No. 350; Gage, 11
Coating weight (avg.), 1.75 oz. per sq.ft.
In exposure test as {Unfabricated sample No. 350
Interior of fence No. 350}



Wire lot No. 351; Gage, 11; Coating weight (avg.), 1.65 oz. per sq.ft.
In exposure test as unfabricated sample No. 351 only.

	Wire Lot No. 451	Wire Lot No. 350	Wire Lot No. 351
Coating weight tests:			
Unfabricated wire	1.71, 1.71	1.72, 1.75, 1.76	1.61, 1.67, 1.68
Other samples	1.95 (Barbed wire)	1.76 (Fence)	....
Preece dips withstood:*			
Unfabricated wire	7, 7, 7, 8, 8	9, 9, 9, 9, 9	5, 5, 6, 6, 7
Other samples	8, 8, 8 (Barbed wire)	7, 7, 7, 7, 7 (Fence)	....
Coat thickness, in.	Min. 0.00263 Max. 0.00275	Min. 0.00294 Max. 0.00313	Min. 0.002 Max. 0.00375
Wrap test performance	Good	Flaked	Checks
Iron content of coating, per cent	0.04	0.02	0.06

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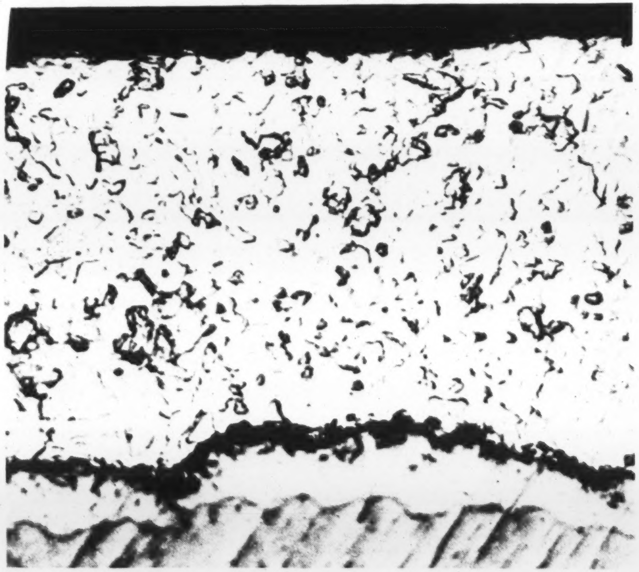
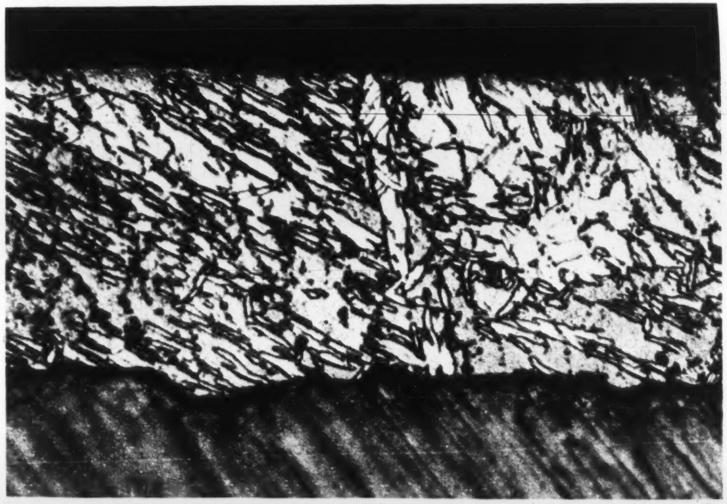
* See note at the end of Table I - K

TABLE I-J.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 352; Gage, 11
Coating weight (avg.), 1.78 oz. per sq.ft.
In exposure test as {Unfabricated sample No. 352
{Interior of fence No. 352



Wire lot No. 250; Gage, 9
Coating weight (avg.), 1.76 oz. per sq.ft.
In exposure test as unfabricated sample No. 250

		Wire Lot No. 352	Wire Lot No. 250
Coating weight test	Unfabricated wire	1.80, 1.81, 1.83	1.72, 1.77, 1.79
	Interior of fence	1.68	....
Preece dips withstood*	Unfabricated wire	5, 5, 5, 6, 6	6, 6, 6, 7, 7
	Interior of fence	5, 7, 8	....
Coating thickness, in.		Min. 0.0015 Max. 0.00425	Min. 0.00075 Max. 0.00375
Wrap test performance		Flaked	Cracks
Iron content of coating, per cent		1.4	0.55

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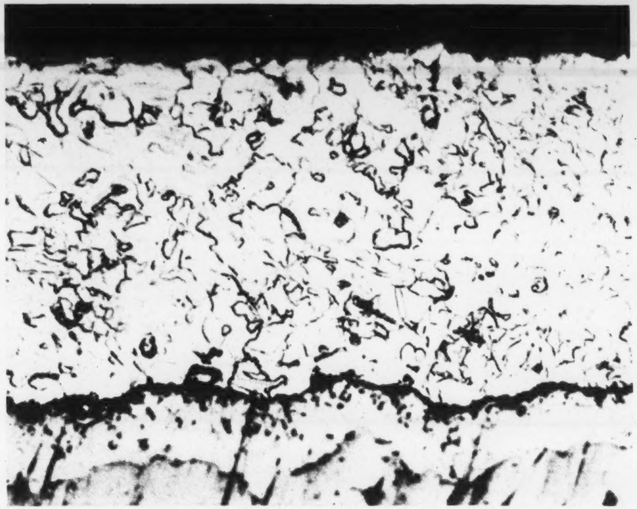
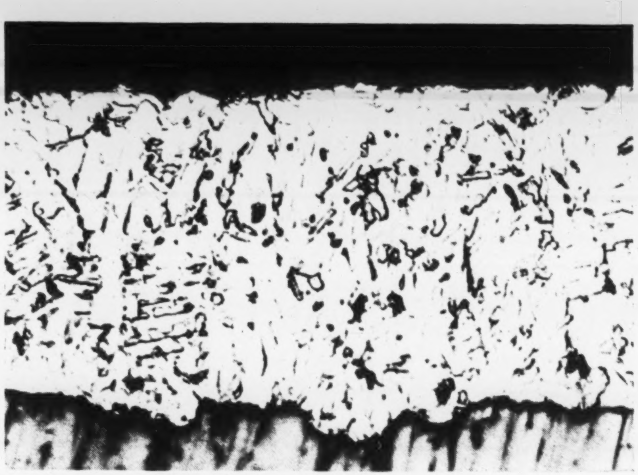
* See note at the end of Table I - K.

TABLE I - J.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 251; Gage, 9
Coating weight (avg.), 1.86 oz. per sq. ft.
In exposure test as {Unfabricated sample No. 251
Top and bottom of fence No. 352



Wire lot No. 252; Gage, 9
Coating weight (avg.), 1.69 oz. per sq.ft.
In exposure test as {Unfabricated sample No. 252
All of fence No. 252

	Wire Lot No. 251	Wire Lot No. 252
Coating weight tests	Unfabricated sample 251: 1.66, 1.68, 1.81 Top of fence 352: 1.99 Bottom of fence 352: 1.91	Unfabricated sample 252: 1.67 Top of fence 252: 1.85 Bottom of fence 252: 1.57
Preece dips withstood*	Unfabricated sample 251: 6, 6, 6, 6 Top of fence 352: 8, 8, 9 Bottom of fence 352: 7, 7, 7	Unfabricated sample 252: 7, 8, 8, Interior of fence 252: 8, 9, 9 Top of fence 252: 7, 9, 10 Bottom of fence 252: 8, 9, 9
Coating thickness, in	Min. 0.0015 Max. 0.004	Min. 0.00275 Max. 0.003
Wrap test performance	Peeled	Flaked
Iron content of coating, per cent	1.6	0.07

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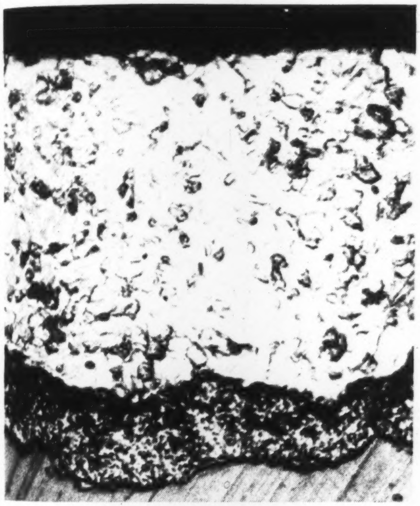
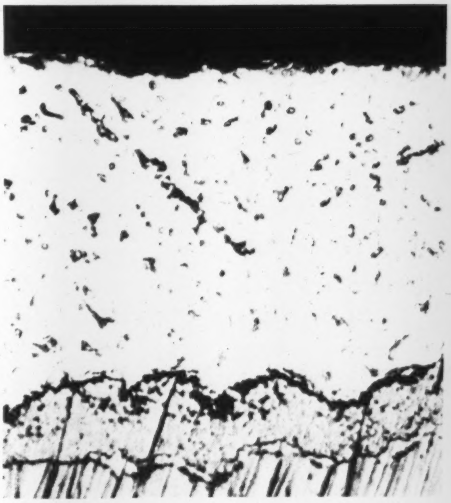
* See note at the end of Table I - K.

TABLE I - J.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 151, deeply etched



Wire lot No. 151, usual etching

Gage, 6; Coating weight (avg.), 1.86 oz. per sq.ft.
In exposure test as unfabricated sample No. 151.

Coating weight tests: 1.62, 1.75, 1.68, 1.99. Preece dips* withstood: 7, 7, 7, 7
Coating thickness, in.: min. 0.00075, max. 0.004
Wrap test performance, cracked; Iron content of coating, 1.5 per cent

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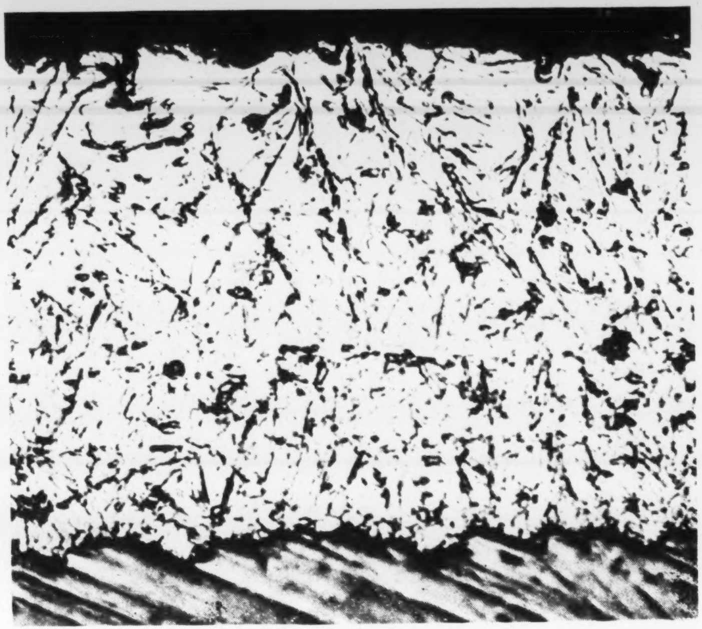
* See note at the end of Table I - K.

TABLE I - K.—ZINC COATED SPECIMENS: EXTRA HEAVY NOMINAL COATING.

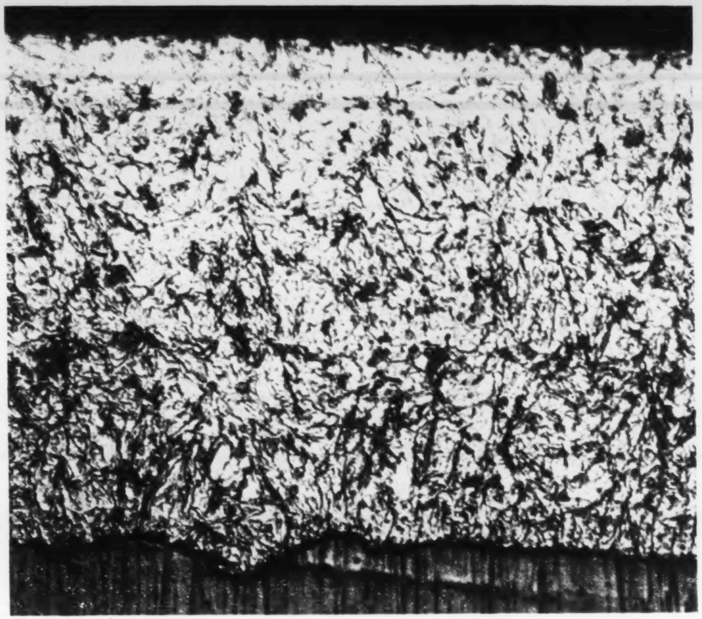
Wire Lot	Breaking Load, lb.	Elongation, in 10 in., per cent	TensileStrength, psi. Figured for Wire		Chemical Analyses of Coatings, per cent				Chemical Analyses of Base Metal, per cent						
			Coated	Stripped	Pb	Cd	Cu	Fe	C	Mn	P	S	Si	Cu	Cr
No. 397.....	940	11.5	82 000	96 200	0.002	N.D.	0.005	0.02	0.12	0.12	0.016	0.032	0.007	0.25	0.08
No. 298.....	1520	6.7	87 200	98 500	0.02	N.D.	0.005	0.01	0.12	0.17	0.017	0.031	0.01	0.24	0.08
No. 299.....	1840	2.2	106 800	125 000	0.001	N.D.	0.008	1.30	0.09	0.40	0.011	0.027	0.10	0.24	0.01

N.D. = Not detected—that is, less than 0.01 per cent.

TABLE I - K.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 397; Gage, 11
Coating weight (avg.), 2.80 oz. per sq.ft.
In exposure test as {Unfabricated sample No. 397
Interior of fence No. 397



Wire lot No. 298; Gage, 9
Coating weight, 2.72 oz. per sq.ft.
In exposure test as: Unfabricated sample No. 298; all of fence No. 298; and top and bottom of fence No. 397

		Coating Weights	Preece Dips Withstood*	Coating Thickness, in.	Wrap Test Performance	Iron in Coating, per cent
Wire Lot No. 397	Unfabricated sample No. 397	2.77, 2.82	12, 12, 12, 12, 12	min. 0.00488 max. 0.00506	Good	0.02
	Interior of fence No. 397	2.79	11, 11, 12, 12, 12			
Wire Lot No. 298	Unfabricated sample No. 298	2.75, 2.77, 2.78, 2.80	11, 11, 11, 11, 11	min. 0.0045 max. 0.00475	Flaked	0.01
	Interior of fence No. 298		11, 11, 11, 11, 11			
	Top of fence No. 298	2.71	11, 11, 11, 11, 11			
	Bottom of fence No. 298	2.74	12, 12, 12, 12, 12			
	Top of fence No. 397	2.71	11, 11, 12, 12, 12			
	Bottom of fence No. 397	2.67	11, 12, 12, 12, 12			

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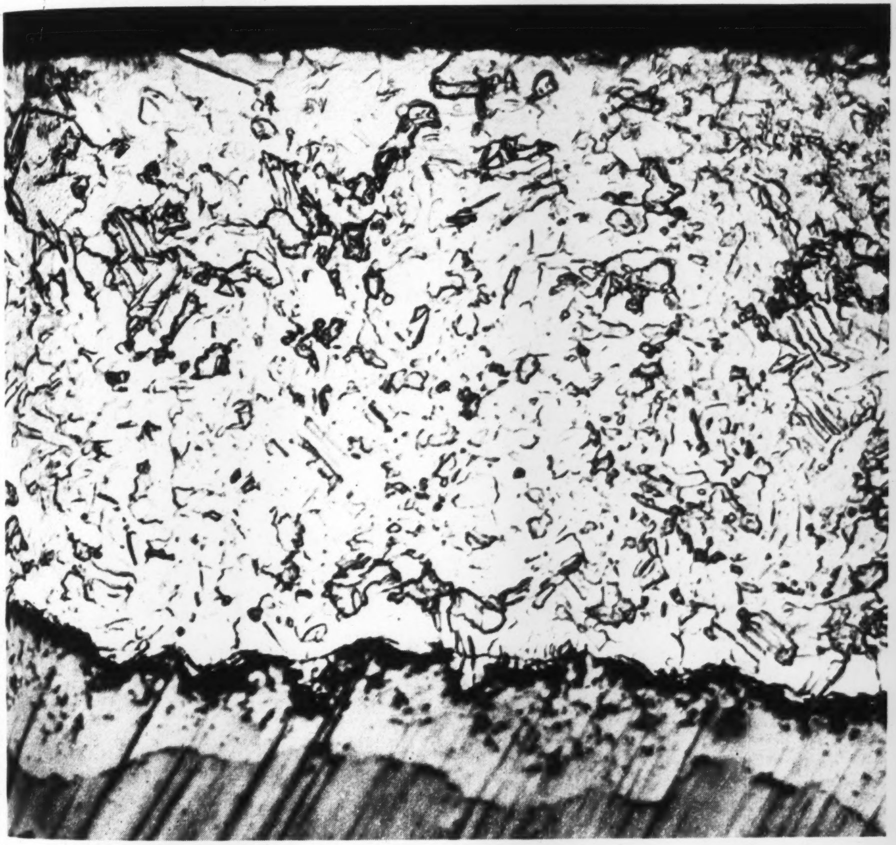
* See note at the end of Table I - K.

TABLE I - K.—ZINC COATED SPECIMENS.—*Cont.*



Wire lot No. 299; Gage, 9; Coating weight (avg.), 3.03 oz. per sq.ft.
In exposure test as unfabricated sample No. 299
Individual tests {Coating weight, 2.34, 2.91, 3.15, 3.31, 3.44 oz. per sq.ft.
Individual tests {Preece dips withstood,* 11, 12, 12
Coating thickness, in.: min. 0.00225, max. 0.00575
Wrap test performance, cracks; Iron content of coating, 1.3 per cent.

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* (Reference note applying to Tables I - A to I - K.) In a number of instances the results of the Preece tests are higher than might be expected from tests made on newly galvanized wire with the same weight and character of coating. The Preece tests were made at the National Bureau of Standards during March and April, 1937. Presumably the samples had been produced about 6 to 12 months before, since most of them were received by the Engineer of Tests in New York in the period of May to September, 1936.

TABLE I - L.—UNCOATED COPPER-BEARING STEEL WIRE SPECIMENS.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi.	In Exposure Test as				Chemical Analyses of Base Metal, per cent						
				Unfabricated Wire	Interior Wire	Top and Bottom Wire	Barbed Wire	C	Mn	P	S	Si	Cu	Cr
No. A - 505[a]	(fence sample, tension tests not made)				No. 505	....	....	0.13	0.43	0.066	0.020	0.04	0.24	0.02
No. 506	520	7.3	115 200	No. 506	No. 506	....	....	0.10	0.45	0.018	0.026	0.12	0.25	0.03
No. 507	590	1.3	131 400	No. 507	....	....	....	0.12	0.39	0.012	0.026	0.07	0.24	0.02
No. 405	470	20.0	62 200	No. 405	No. 405	....	No. 406	0.12	0.39	0.007	0.021	0.07	0.24	0.02
No. 406	460	17.8	61 100	No. 406	No. 406	....	No. 405	0.13	0.43	0.053	0.024	0.03	0.23	0.02
No. 305	1070	8.3	96 400	No. 305	No. 305	No. 506	....	0.10	0.46	0.012	0.024	0.14	0.24	0.02
No. 306	700	19.8	63 400	No. 306	No. 306	No. 505	....	0.12	0.44	0.055	0.022	0.03	0.22	0.03
No. 205	1110	16.5	65 100	No. 205	No. 205	No. 205	....	0.12	0.39	0.007	0.026	0.07	0.24	0.02
No. 206	1480	11.2	84 700	No. 206	No. 206	No. 206 No. 305	....	0.09	0.46	0.016	0.023	0.13	0.25	0.02
No. 207[a]	(fence sample, tension tests not made)				....	No. 306	....	0.12	0.41	0.061	0.022	0.04	0.24	0.03
No. 102	2110	10.8	73 500	No. 102	....	....	....	0.12	0.39	0.006	0.025	0.07	0.24	0.02
No. 106	2430	3.3	83 100	No. 106	....	....	....	0.12	0.38	0.009	0.027	0.08	0.23	0.02

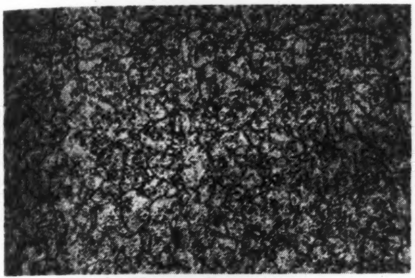
[a] Analysis of A - 505 made on wire cut from interior of fence 505.
Analysis of 207 made on wire cut from top and bottom of fence 306.

TABLE I - M.—UNCOATED LOW COPPER CONTENT STEEL WIRE SPECIMENS.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Tensile Strength, psi.	In Exposure Test as				Chemical Analyses of Base Metal, per cent						
				Unfabricated Wire	Interior Wire	Top and Bottom Wire	Barbed Wire	C	Mn	P	S	Si	Cu	Cr
No. 501	500	7.3	110 500	No. 501	......	......	......	0.10	0.36	0.016	0.016	0.14	0.07	0.02
No. 400	470	19.2	62 200	No. 400	......	......	......	0.13	0.36	0.058	0.024	0.10	0.08	0.03
No. 401	440	17.2	58 700	No. 401	......	......	......	0.09	0.41	0.011	0.024	0.08	0.05	0.01
No. 300	730	19.5	64 600	No. 300	......	......	......	0.14	0.37	0.060	0.025	0.09	0.08	0.03
No. 302	1100	7.5	97 000	No. 302	......	......	......	0.10	0.36	0.009	0.017	0.16	0.07	0.02
No. 200	1010	14.8	59 600	No. 200	......	......	......	0.10	0.41	0.010	0.027	0.08	0.06	0.02
No. 202	1640	6.3	94 100	No. 202	......	......	......	0.11	0.38	0.013	0.018	0.16	0.07	0.02
No. 101	2330	6.0	79 500	No. 101	......	......	......	0.11	0.36	0.013	0.018	0.15	0.06	0.02
No. 105	2750	5.0	93 800	No. 105	......	......	......	0.13	0.65	0.008	0.026	0.01	0.05	0.01

TABLE I-N.—UNCOATED CORROSION-RESISTANT STEEL SPECIMENS.

(All micrographs in this table had an original magnification of 500 diameters and were reduced to ¾ of their size in reproductions.)



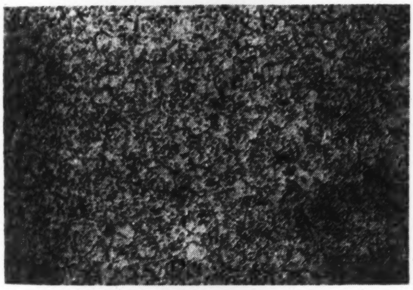
Wire lot No. 001; Gage, 12
12 to 14 per cent Cr—Cold drawn

In exposure test as:
Unfabricated sample No. 001
All wires of fence No. 001

Test results all obtained on unfabricated wire sample.

Breaking load, 1230 lb.; Elongation in 10 in., 3 per cent
Tensile strength, 141,800 psi.
Diameter, 0.105 in.
Chemical analyses of base metal, per cent

C	0.08	Ni	0.26
Mn	0.32	Cr	12.50
Si	—		

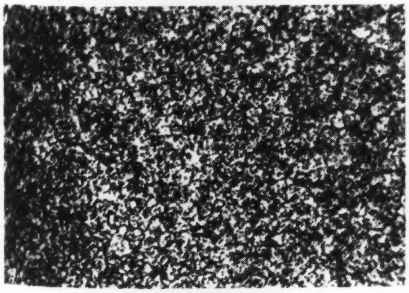


Wire lot No. 004; Gage, 9
12 to 14 per cent Cr—Cold drawn

In exposure test as:
Unfabricated sample No. 004

Test results all obtained on unfabricated wire sample.

Breaking load, 2420 lb.; Elongation in 10 in., 3.5 per cent
Tensile strength, 140,700 psi.
Diameter, 0.148 in.
Chemical analyses of base metal:
Same as wire lot No. 001



Wire lot No. 005; Gage, 17
12 to 14 per cent Cr—Cold drawn

In exposure test as:
Unfabricated sample No. 005

Test results all obtained on unfabricated wire sample.

Breaking load, 320 lb.; Elongation in 10 in., 2.1 per cent
Tensile strength, 140,200 psi.
Diameter, 0.053 in.
Chemical analyses of base metal:
Same as wire lot No. 001

TABLE I - N.—UNCOATED CORROSION-RESISTANT STEEL SPECIMENS.—*Cont.*

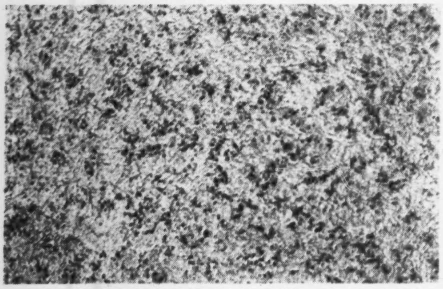
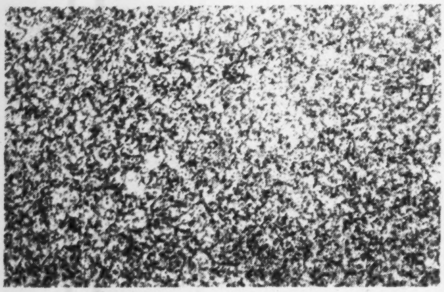
Wire lot No. 002; Gage, 13 12 to 14 per cent Cr—Air quenched	In exposure test as: Unfabricated sample No. 002 All wires of fence No. 002 Breaking load, 1310 lb.; Elongation in 10 in., 4.2 per cent Tensile strength, 174,700 psi. Diameter, 0.098 in. Chemical analyses of base metal, per cent C. . . . . 0.07 Ni . . . . 0.26 Mn . . . 0.32 Cr . . . 12.50 Si . . . . . —	Test results all obtained on unfabricated wire sample
Wire lot No. 006; Gage, 10 12 to 14 per cent Cr—Air quenched	In exposure test as: Unfabricated sample No. 006 Breaking load, 2480 lb.; Elongation in 10 in., 4 per cent Tensile strength, 173,100 psi. Diameter, 0.135 in. Chemical analyses of base metal: Same as wire lot No. 002	Test results all obtained on unfabricated wire sample
No micrograph made; intended to be like wire lots Nos. 002 and 006. Wire lot No. 007; Gage, 18 12 to 14 per cent Cr—Air quenched	In exposure test as: Unfabricated sample No. 007 Breaking load, 280 lb.; Elongation in 10 in., 4.7 per cent Tensile strength, 163,700 psi. Diameter, 0.047 in. Chemical analyses of base metal: Same as wire lot No. 002	Test results all obtained on unfabricated wire sample

TABLE I - N.—UNCOATED CORROSION-RESISTANT STEEL SPECIMENS.—*Cont.*

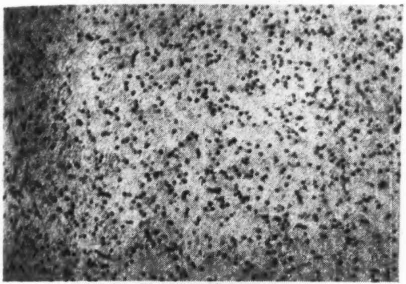
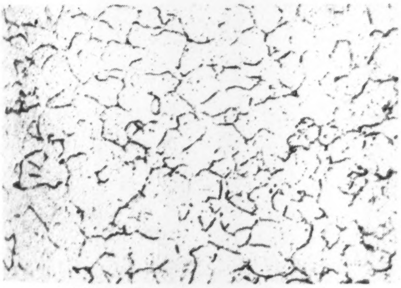
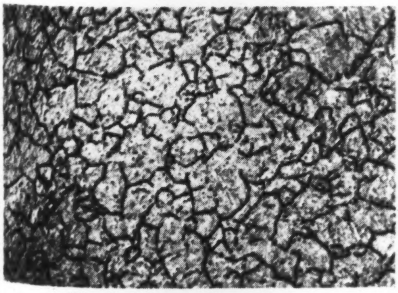
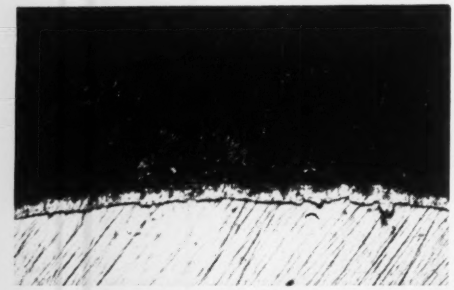
No micrograph made; intended to be like wire lots Nos. 008 and 009. Wire lot No. 003; Gage, 15 18 per cent Cr—8 per cent Ni	In exposure test as: Unfabricated sample No. 003 All wires of fence No. 003 Breaking load, 1280 lb.; Elongation in 10 in., 0.5 per cent Tensile strength, 304,800 psi. Diameter, 0.073 in. Chemical analyses of base metal, per cent C......0.06 Ni.... 8.73 Mn....0.31 Cr....18.70 Si...... —	Test results all obtained on unfabricated wire sample.
 Wire lot No. 008; Gage, 12 18 per cent Cr—8 per cent Ni	In exposure test as: Unfabricated sample No. 008 Breaking load, 2510 lb.; Elongation in 10 in., 2.3 per cent Tensile strength, 285,600 psi. Diameter, 0.106 in. Chemical analyses of base metal: Same as wire lot No. 003	Test results all obtained on unfabricated wire sample.
 Wire lot No. 009; Gage, 20 18 per cent Cr—8 per cent Ni	In exposure test as: Unfabricated sample No. 009 Breaking load, 290 lb.; Elongation (kinked when broke) Tensile strength, 290,000 psi. Diameter, 0.035 in. Chemical analyses of base metal, per cent C......0.06 Ni.... 8.71 Mn....0.31 Cr....18.70 Si...... —	Test results all obtained on unfabricated wire sample.
 Wire lot No. 015; Gage, 14 18 per cent Cr—8 per cent Ni	In exposure test as: Unfabricated sample No. 015 Breaking load, 1250 lb.; Elongation in 10 in., 0.8 per cent Tensile strength, 240,400 psi. Diameter, 0.081 in. Chemical analyses of base metal, per cent C......0.18 Ni.... 9.10 Mn....0.55 Cr....18.7 Si......0.40	Test results all obtained on unfabricated wire sample.

TABLE I - O.—LEAD-COATED SPECIMENS.

(All micrographs in this table had an original magnification of 500 diameters and were reduced to ¾ of their size in reproductions.)



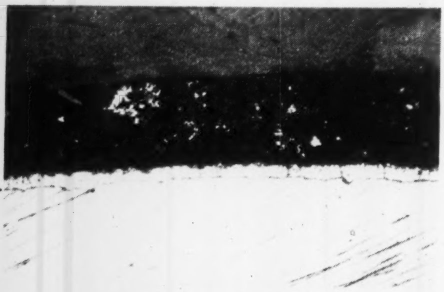
Wire lot No. 0.40; Gage, 6
Coating weight, 1.40 oz. per sq.ft.

In exposure test as:
Unfabricated sample No. 040

Test results all obtained on unfabricated wire sample.

Breaking load, 1790 lb.; Elongation in 10 in., 9.5 per cent
Tensile strength (figured for coated wire), 61,600 psi.
Weight of coating, 1.40 oz. per sq.ft.
Chemical analyses of base metal, per cent

C	0.08	S	0.019	Ni	<0.1
Mn	0.32	Si	0.01	Cr	0.06
P	0.018	Cu	0.29	Mo	<0.02



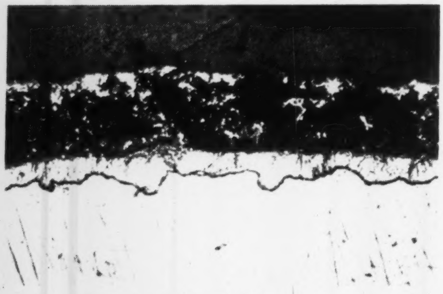
Wire lot No. 041; Gage, 9
Coating weight, 1.48 oz. per sq.ft.

In exposure test as:
Unfabricated sample No. 041
Interior of fence No. 040

Test results all obtained on unfabricated wire sample.

Breaking load, 1070 lb.; Elongation in 10 in., 12.8 per cent
Tensile strength (figured for coated wire), 62,400 psi.
Weight of coating, 1.48 oz. per sq.ft.
Chemical analyses of base metal, per cent

C	0.06	S	0.019	Ni	<0.1
Mn	0.27	Si	0.006	Cr	0.02
P	0.045	Cu	0.23	Mo	<0.02



Wire lot No. 0.42; Gage, 11
Coating weight, 1.68 oz. per sq.ft.

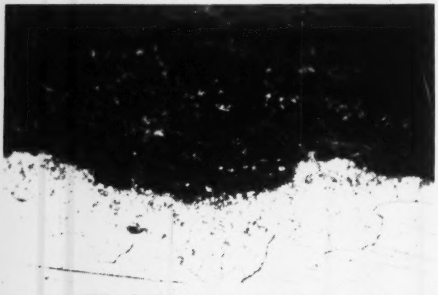
In exposure test as:
Unfabricated sample No. 042
Barbed wire No. 045

Test results all obtained on unfabricated wire sample, except as noted.

Breaking load, 670 lb.; Elongation in 10 in., 13.0 per cent
Tensile strength (figured for coated wire), 58,300 psi.
Weight of coating, 1.68 oz. per sq.ft.
Chemical analyses of base metal, per cent

C	0.04	S	0.015	Ni	<0.1
Mn	0.25	Si	0.01	Cr	0.02
P	0.009	Cu	0.24	Mo	<0.02

Weight of coating on barbed wire No. 045, 1.83 oz. per sq. ft.



Wire lot No. 0.43; Gage, 14.5
Coating weight, 1.90 oz. per sq.ft.

In exposure test as:
Unfabricated sample No. 043

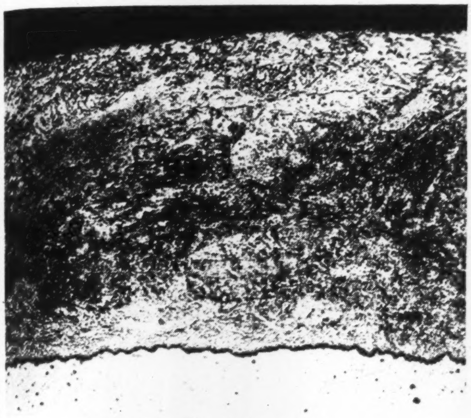
Test results all obtained on unfabricated wire sample.

Breaking load, 300 lb.; Elongation in 10 in., 17.1 per cent
Tensile strength (figured for coated wire), 56,600 psi.
Weight of coating, 1.90 oz. per sq.ft.
Chemical analyses of base metal, per cent

C	0.10	S	0.016	Ni	<0.1
Mn	0.40	Si	0.008	Cr	0.03
P	0.007	Cu	0.029	Mo	<0.02

TABLE I-P—COPPER-COVERED SPECIMENS.

(All micrographs in this table had an original magnification of 350 diameters and were reduced to ¾ of their size in reproductions.)



Wire lot No. 021; Gage, 11
Coating, 7.42 oz. per sq.ft.

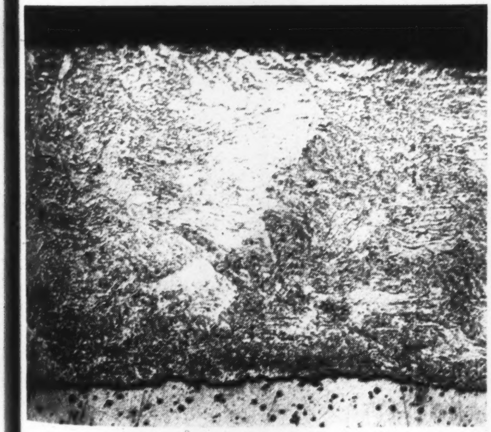
In exposure test as:
Unfabricated sample No. 021
Interior of fence No. 020
Barbed wire No. 025

Test results all obtained on unfabricated wire, except as noted.

Breaking load, 1640 lb.
Tensile strength (figured for coated wires), 140,200 psi.
Weight of coating, 7.42 oz. per sq.ft.
Chemical analyses of base metal, per cent

C	0.18	S	0.017	Ni	<0.10
Mn	2.04	Si	0.250	Cr	0.06
P	0.016	Cu	0.120	Mo	<0.02

Weight of coating on barbed wire No. 025, 3.97 oz. per sq. ft.



Wire lot No. 022; Gage, 9
Coating, 9.24 oz. per sq.ft.

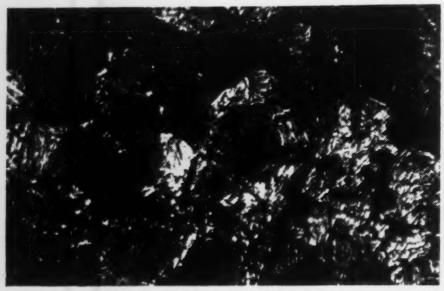
In exposure test as:
Unfabricated sample No. 022
Top and bottom of fence No. 020

Test results all obtained on unfabricated wire.

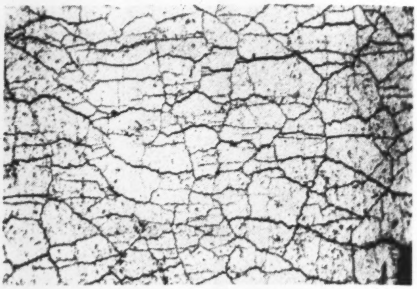
Breaking load, 2320 lb.
Tensile strength (figured for coated wires), 133,200 psi.
Weight of coating, 9.24 oz. per sq.ft.
Chemical analyses of base metal, per cent

C	0.18	S	0.017	Ni	<0.10
Mn	2.04	Si	0.250	Cr	0.06
P	0.015	Cu	0.110	Mo	<0.02

ADDITIONAL ILLUSTRATIONS OF LEAD-COATED AND COPPER-COVERED WIRES



(*A*) Lead Coating—structure of outer layer (long section).



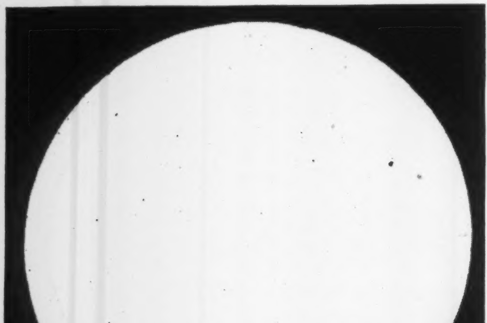
(*B*) Lead Coating—structure of bonding layer (long section).

Original magnification. × 500. Reduced to ¾ original size in reproduction.

To prepare micrographs *A* and *B*, specimen was mounted in sulfur without disturbing the surface of the coating, and polished with levigated alumina to prepare longitudinal sections.

A is a photograph of the surface disclosed before reaching the bonding layer (etching reagent: 3 parts acetic acid + 1 part hydrogen peroxide).

B is a photograph of the surface disclosed by polishing down to the bonding layer (etching reagent: 10 g. chromic acid + 1.5 g. sodium sulfate in 100 ml. of water).



Cross-section of sample No. B - 022 (copper covered wire) showing steel core and outer layer of copper coating; 30 per cent conductivity. Original magnification: × 25. Reduced to ¾ original size in reproduction.

TABLE II.—WIRE STRAND SPECIMENS.

Strand[a]	Weight of Coating, oz. per sq. ft.		Preece Dips Withstood
	Nominal	Stripping Test	
No. D345	0.80 to 0.95	0.68-0.69	4-4-4-4-4
No. D346	0.80 to 0.95	0.88	6-6-6
No. D347	0.80 to 0.95	0.87	6-6-6
No. D348	0.80 to 0.95	0.93	5-6-5
No. D360	1.00 to 1.20	1.10	6-6-6
No. D361	1.00 to 1.20	1.17	5-7-6
No. D362	1.00 to 1.20	1.02-1.04	7-8-7
No. D365	1.30 to 1.50	1.51	9-9-9
No. D366	1.30 to 1.50	1.39	7-8-8
No. D367	1.30 to 1.50	1.32	9-9-10
No. D371	1.60 to 1.80	1.71	9-9-9
No. D375	2.40 to 2.60	2.47	11-11-11
No. D045	Lead-covered steel, 1.96 oz. per sq. ft.		

[a] All except D045 are zinc coated, Siemens-Martin steel.

TABLE III.—CHAIN LINK FENCE SPECIMENS.

Fence	Gage	Weight of Coating, oz. per sq. ft.		Preece Dips Withstood
		Nominal	Stripping Test	
Zinc-Coated, Copper-Bearing Steel, Galvanized Before Weaving				
No. E280	No 9	0.50 max.	0.29	2-2-2-2[b]
No. E281	No. 9	0.50 max.	0.52	3-2-2-2
No. E282	No. 9	0.50 max.	0.37	3-3-3-3
No. E185	No. 6	1.20 to 1.50	1.22	6-6-6[c]
No. E285	No. 9	1.20 to 1.50	1.09-1.16	6-6-6[d]
No. E290	No. 9	2.40 to 3.00	2.92	9-10-9
No. E291	No. 9	2.40 to 3.00	1.91-2.27	5-6-6
Zinc-Coated, Copper-Bearing Steel, Galvanized After Weaving				
No. H280	No. 9	0.50 max.	1.60	4-4-4
No. H185	No. 6	1.20 to 1.50	1.83	6-6-6
No. H186	No. 6	1.20 to 1.50	1.60	6-6-6
No. H187	No. 6	1.20 to 1.50	1.61	9-9-9
No. H188	No. 6	1.20 to 1.50	1.55	4-6-4-4
No. H285	No. 9	1.20 to 1.50	1.36	6-6-6
No. H286	No. 9	1.20 to 1.50	1.97	7-7-7
No. H287	No. 9	1.20 to 1.50	1.46	4-4-4
No. H288	No. 9	1.20 to 1.50	1.74	8-8-8
No. H289[a]	No. 9	1.20 to 1.50	1.40	5-5-5
No. H290	No. 9	2.40 to 3.00	4.21	13-13-13
L050	9	Lead-coated steel, 1.75 oz. per sq. ft.		
K030	0.128d	Copper-covered steel, 8.52 oz. per sq. ft.		
J011	14	Uncoated corrosion-resistant steel.		

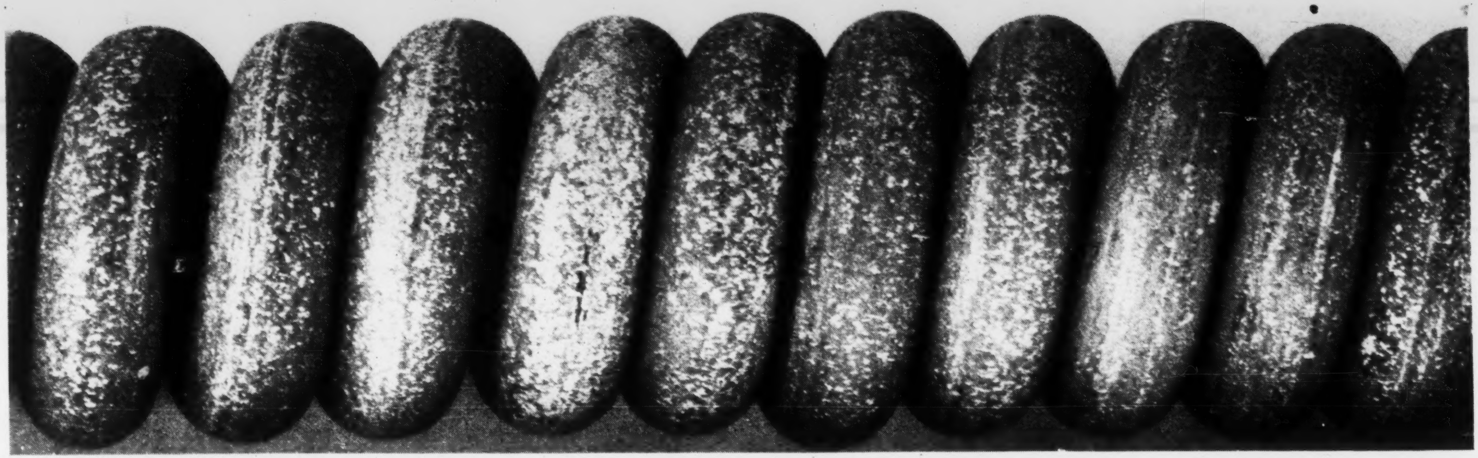
[a] H289: While this sample has an H number, its appearance indicates that it was galvanized before weaving.

[b] Failed on bend.

[c] Initial failure on fourth dip on link bend.

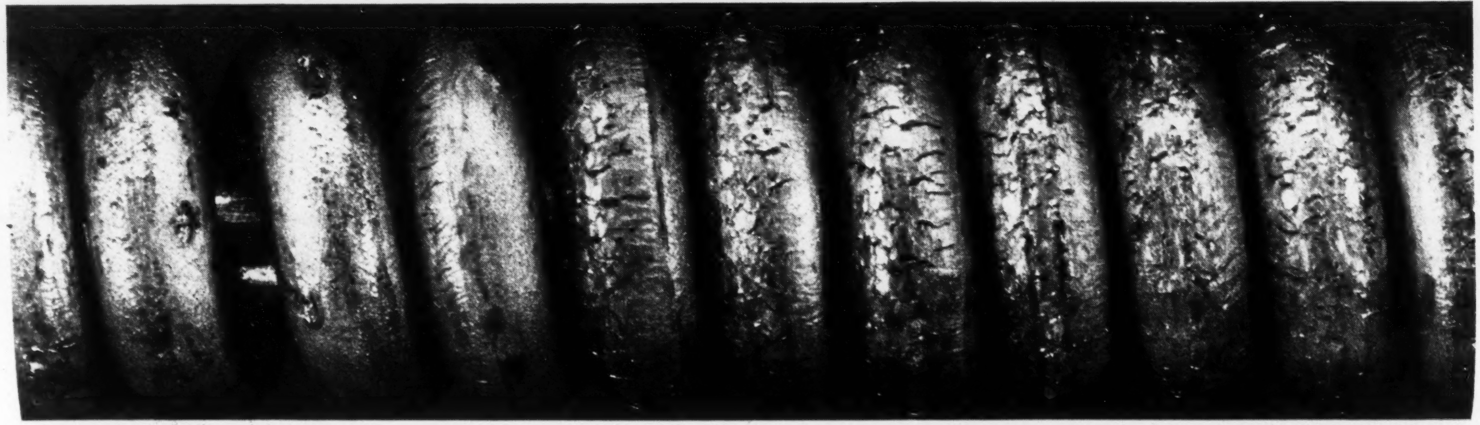
[d] One specimen failed on bend on second dip

TYPICAL ILLUSTRATIONS OF WRAP TEST PERFORMANCES



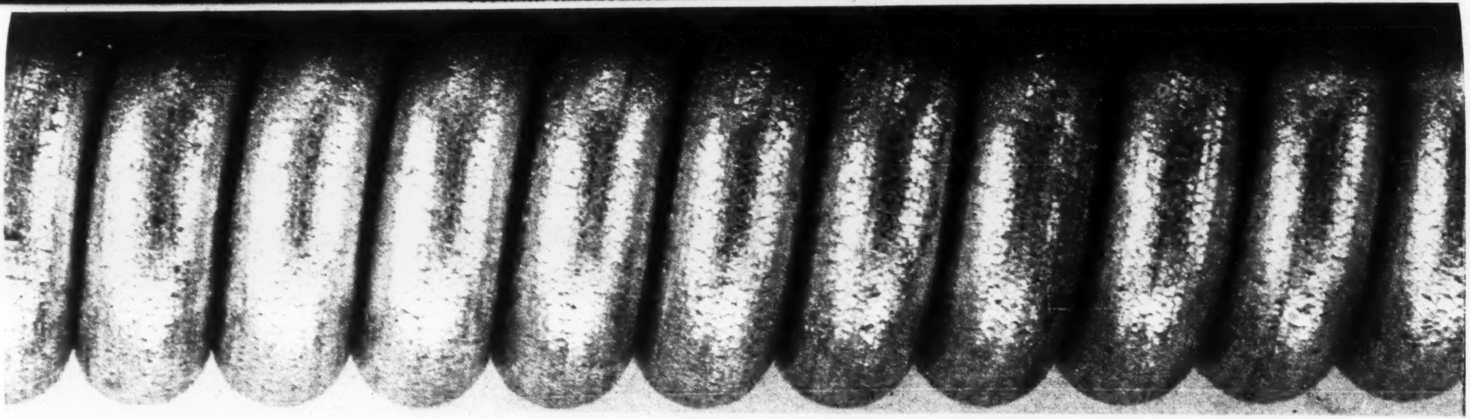
The condition of "flaking" referred to in Table I.

Wire Lot No. 225 (×5)

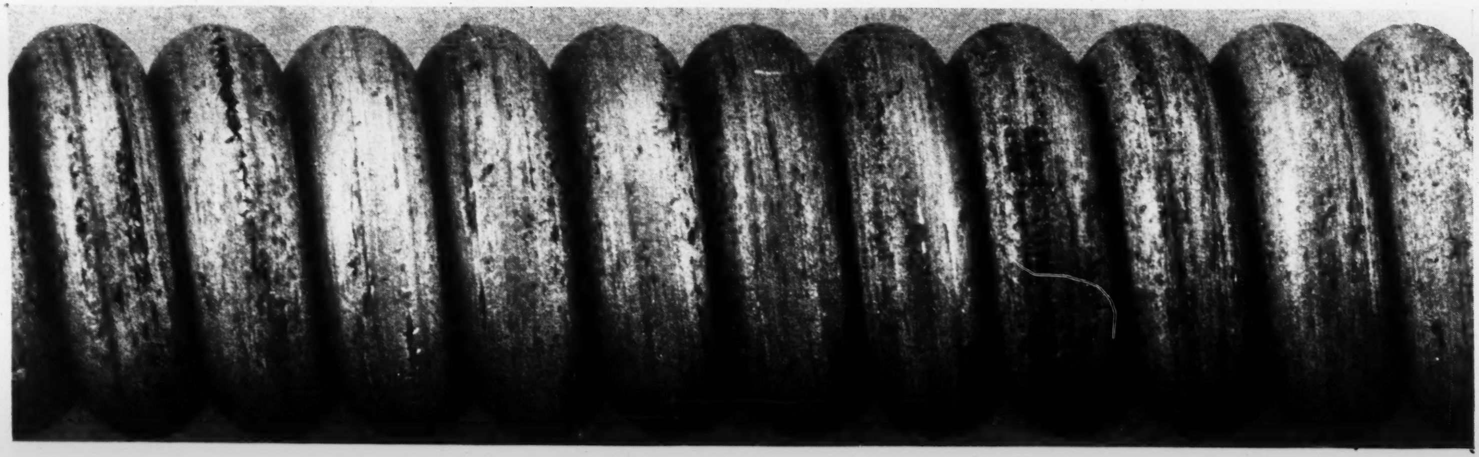


The condition of "peeled" referred to in Table I.

Wire Lot No. [illegible]



The condition of "checks" referred to in Table I. Wire Lot No. 298 (×5)



The condition of "cracks" referred to in Table I. Wire Lot No. 299 (×5)

METHODS OF TESTING

The methods of testing employed at the National Bureau of Standards for determining the chemical and physical characteristics of the wire and wire products under test are given below.

Chemical Analysis of Base Metal:

The chemical analyses of the base metal of galvanized steel, stainless steels, lead-covered steels and copper-covered steels were made in accordance with the Society's Tentative Methods of Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron and Wrought Iron (A.S.T.M. Designation: E 30 – 36 T).[1] The analyses included the determination of the amounts of carbon, manganese, phosphorus, sulfur, silicon, copper, nickel, chromium, and molybdenum.

The following notations show the particular method of analysis followed in instances where alternative methods are listed in the specification:

BASIS METAL OF ZINC-, LEAD-, AND COPPER-COVERED STEELS

Mn—Persulfate-Arsenite method.
P —Alkalimetric method.
S —Evolution method.
Si —Sulfuric acid method.
Cu —Thiocyanate method[2]
Ni —Dimethylgloxime method.
Cr —Persulfate Oxidation method.
Mo—Colorimetric method.

STAINLESS STEELS

Mn—ZnO—persulfate-arsenite method.
Si —Sulfuric acid method.
Ni —Dimethylgloxime method.
Cr —Persulfate oxidation—potentiometric titration.

The methods for chemical analyses of zinc coatings for lead, copper, cadmium, tin, and iron follow:

Determination of Lead, Copper, Cadmium, and Tin in Zinc Coatings of Galvanized Wires:

Take enough wire to give 20 to 25 g. of coating. Cut into 10 to 12-in. lengths and weigh. Bend the short sections to form a narrow U and strip several pieces at a time by immersing in 500 ml. of HCl (sp. gr. 1.19) contained in a 1-liter cylinder. When vigorous action ceases and there is no longer any black deposit on the wires, immediately remove from the acid and wash with water, catching the washings in a 1-liter beaker. Dry the washed wires and weigh. The difference in weight before and after stripping represents the weight of the coating.

Transfer the HCl solution of the coating to the beaker containing the washings, add 1 g. $NaClO_3$ and carefully evaporate to a volume of 75 to 100 ml., taking care *not to boil*, as tin will be lost by volatilization if boiling occurs. A qualitative test for tin is made at this point; conveniently made on the cooled solution by the flame test.[3] If tin is found to be present, dilute to 200 ml. and take a 40-ml. aliquot portion for the tin determination,[4] and use the remaining 160 ml. aliquot portion for the determination of lead, copper, and cadmium.

Transfer the 160-ml. portion if tin is present, or all of the solution if tin is absent, to a 600-ml. beaker, add 10 g. tartaric acid, NH_4OH until the white precipitate of $Zn(OH)_2$ just redissolves, and then a 50-ml. excess. Heat to 80 C. and while stirring, preferably with a mechanical stirrer, slowly add 20 ml. of $(NH_4)_2\,S_x$ solution.[5] Continue stirring for 5 min. Place on a steam bath and stir the precipitate every 15 min. over a period of 2 hr. and finally let stand on a steam bath overnight.

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[1] 1936 A.S.T.M. Methods of Chemical Analysis of Metals, p. 1.

[2] See Lundell, Hoffman, and Bright, "Chemical Analysis of Iron and Steel," p. 271, John Wiley and Sons, New York City.

[3] A few small pieces of pure zinc are added to 25 ml. of the acid solution of coating and immediately the end of a clean test tube, one-third full of cool water, is immersed in this solution. The end of the test tube, wet with the solution of coating, is then held in the hottest part of a bunsen flame. If tin is present the outer surface of the test tube will glow with a characteristic blue color. The blue color is easily seen with 1 mg. of tin in 25 ml. of solution and with a little practice 0.1 mg. may be detected in 25 ml. (The 25-ml. portion used for the qualitative test is added to the main solution.)

[4] If tin is detected, it is then determined volumetrically by reduction with granulated lead in HCl solution and oxidized with a standard solution of iodine as described by G. E. F. Lundell and J. A. Scherrer, *Journal of Industrial and Engineering Chemistry*, Vol. 14, p. 426 (1922).

Filter off the sulfides on a 15-cm. paper of close texture, wash the beaker twice and the precipitate and paper 4 times with a hot solution of NH_4Cl (3 per cent), allowing the funnel to drain each time. Place the filter paper and precipitate in the original beaker, add 75 ml. of diluted HNO_3 (1:1), and digest on a hot plate until the sulfides are decomposed. Filter off the paper pulp and sulfur, and wash 6 or 8 times with hot water. Evaporate the filtrate until salts separate, wash down the sides of the beaker, add 25 ml. of HNO_3 (sp. gr. 1.42) and evaporate nearly to dryness. Add 25 ml. HNO_3 (sp. gr. 1.42) and again evaporate to a small volume. Treat with 50 ml. hot water and, if lead salts do not dissolve, add 5 ml. portions of HNO_3 (sp. gr. 1.42), heating after each addition, until all salts are in solution. Cool and neutralize with NH_4OH. Add 7 ml. of HNO_3 (sp. gr. 1.42), transfer to a 250-ml. beaker, and dilute to a volume of 200 ml.

Copper and lead are determined in this solution by electrolytic deposition as follows: Insert the weighed platinum-gauze cathode and anode, cover the beaker with split watch glasses and electrolyze, preferably overnight, with a current of 0.2 amp. Rinse off the cover glasses, continue the electrolysis for about 20 min., and then while the current is still on, lower the beaker and at the same time, wash the electrodes thoroughly with water. Rinse the cathode with alcohol and dry for 1 min. at 100 C.; cool, and weigh as Cu. Dry the anode for 30 min. at 110 C., cool, and weigh as PbO_2.

To the electrolyte add 2 g. of tartaric acid, 55 ml. NH_4OH, heat to 80 C. and add $(NH_4)_2\,S_x$ while stirring, until a small amount of zinc is precipitated. Allow to stand on a steam bath overnight. Filter off the sulfides and wash twice with a hot solution of NH_4Cl (3 per cent). Return the precipitate and filter paper to the original beaker, add 75 ml. of diluted H_2SO_4 (1:5) and digest on the hot plate until sulfides are in solution. Filter off the paper pulp and sulfur, and wash thoroughly with hot water. Dilute the filtrate to 400 ml. and pass a stream of H_2S through the solution for 30 min. It may be necessary to add a drop or two of NH_4OH to start the precipitation of CdS. Let the precipitate settle, and filter through a paper of close texture. Wash 4 or 5 times with diluted H_2SO_4 (3:97) saturated with H_2S.

Dissolve the precipitate in 25 ml. of diluted H_2SO_4 (1:5), filter, and wash thoroughly with hot water. Add one drop phenolphthalein indicator and neutralize (just to pink) with a solution of KOH (15 per cent), cool, and add a solution of KCN (10 per cent) drop by drop until the $Cd(OH)_2$ just dissolves. Carefully avoid an excess. Dilute to 225 ml. and electrolyze, using a weighed platinum-gauze cathode and a current of 0.2 amp. At the end of 6 or 7 hr., wash the cover glass and sides of the beaker and continue the electrolysis for 20 min. If the newly exposed surface of the cathode remains bright, stop the current, remove the cathode immediately, and quickly rinse with water, then with alcohol. Dry at 100 C. for 20 min., cool, and weigh.

REFERENCES:

B. H. Strom, ***Engineering Mining Journal***, Vol. 131, p. 465 (1931).

Hillebrand and Lundell, "Applied Inorganic Analysis," John Wiley and Sons, New York City (1929).

F. Feigl "Qual Analyse mit Hilfe von Tüpfel Reaktionen," *Acad. Verlag*, Leipzig (1931).

Determination of Iron in Zinc Coatings:

The iron in the zinc coating was determined in accordance with the procedure outlined in the appendix on "Determination of Iron in Zinc (Galvanized) Coatings," to the Standard Methods of

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[5] Five hundred ml. NH_4OH (sp. gr. 0.90), containing an excess of sulfur is saturated with H_2S; 200 ml. NH_4OH is added and H_2S is passed into the mixture for 2 hr.; the solution is then filtered and 100 ml. NH_4OH is added.

Determining Weight and Uniformity of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 – 33).[6] The zinc coatings were stripped with diluted H_2SO_4 (1:24).

Methods for Determining Weight of Zinc Coatings on Wires:

Plain Wires.—Stripping tests to determine the weight of zinc coating, were made in HCl (sp. gr. 1.19) containing 5 ml. inhibitor solution (1 g. antimony trioxide dissolved in 50 ml. HCl) to each 100 ml. of HCl. The specimen, approximately 30 in. in length, was cleaned with benzol, carbon tetrachloride, and alcohol and weighed to the nearest 0.01 g. The specimen was allowed to remain in the stripping solution until the violent reaction ceased and was then washed in water and wiped dry before reweighing.

The diameter was measured to the nearest 0.001 in., the average of two measurements at right angles to each other being used. Calculations were made by the following formula:

$$\text{Ounces zinc per square foot of stripped wire surface} = 163\,dr,$$

where:

d = the diameter in inches of stripped wire,

$$r = \frac{\text{original weight} - \text{stripped weight}}{\text{stripped weight.}}$$

Farm Fence.—Specimens for determining the weight of coating on the farm fence were cut as short sections of the line wires between the stay wires. In this way it was possible to avoid the necessity of removing the twist of the stay wire from around the line wire and the possibility of damaging the coating in these portions. Separate results are reported on the top and bottom line wires. The testing procedure followed was the same as for plain wire.

Chain Link Fence, Galvanized Before Weaving.—Specimens were cut from two picket wires of the chain link fence samples to determine the weight of coating, and the results for the individual pickets as well as the average of the two are reported. The procedure for testing was the same as for plain wire.

Chain Link Fence, Galvanized After Weaving.—A sample of the fabric 12 by 12 in. was stripped and the "over-all" result for weight of coating reported.

Barbed Wire.—The barbs were removed from the specimen before determining the weight of coating by stripping. Both wires were stripped of the coating and the average weight reported as well as the individual determinations. The test procedure was the same as for plain wire.

In determining the weight of coating on the sample galvanized after fabrication, the barbs were not removed from the strand.

Strand Wires.—Each of seven wires constituting the strand sample was stripped to determine the weight of coating and the weight reported is the average of the seven constituent wires. The test procedure followed was the same as for plain wire.

Methods for the Preece Testing of Galvanized Wires:

Plain Wires.—The copper sulfate solution used in determining the uniformity of the zinc coatings was prepared with analytical cupric sulfate ($CuSO_4 \cdot 5H_2O$), the solution having a specific gravity of 1.186 at 18 C. The specific gravity was determined with a hydrometer calibrated at 15 C./4 C., and check determinations made at intervals. Cupric hydroxide ($CU(OH)_2$) was added to neutralize the solution before use. The pH (3.33) measurement was made with a glass electrode.

Samples approximately 6 in. in length

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[6] 1936 Book of A.S.T.M. Standards, Part I, p. 402.

were cleaned with benzol, carbon tetrachloride, and alcohol. Some that appeared to be slightly corroded were rubbed lightly with magnesium oxide in order to remove the corrosion products. The wire specimens were tested in lots of five. After each 1-min. immersion, the specimens were washed in water and wiped dry. A "false end point," or premature precipitation of copper, appeared on some samples after the first dip. In some instances after the second, third, or fourth dip, copper deposits appeared in small dots. The solution (maintained at a temperature of 18 C.) was changed after the complete test of each set of five specimens.

Farm Fence.—Preece test results to determine the uniformity of coating on the farm fence samples are reported separately on the top and bottom line wires. A premature end point appeared on some samples and was removed by rubbing *lightly* over the metallic copper deposit with a fine grade of steel wool. The testing procedure was the same as for plain wire.

Chain Link Fence.—Specimens were cut from three of the wires in the chain link fence samples for determining the uniformity of coating. The samples were not straightened prior to testing to avoid the possibility of damaging the coating. In some instances, an initial failure occurred at the bend in the specimen before the end point was reached elsewhere. The test procedure was the same as for plain wire.

Barbed Wire.—The two wires were tested for uniformity of coating after the barbs had been removed. The procedure followed was the same as for plain wire.

Strand Wires.—Each of the constituent wires in the strand sample was tested to determine the uniformity of coating. The test procedure was the same as for plain wire.

Methods for Measuring and Weighing "Galvanized Steel Wire" Weight Loss Specimens:

The specimens for loss-of-weight tests were weighed and carefully measured at 68 C. The diameter measurements were accurate to 0.0005 in. The length measurements were accurate to 0.002 in. for 6, 9, 11, and 12½ gage wires, and to 0.003 in. for 14½ gage wires. All wires were weighed in air to the nearest 0.001 g., and corrected to weight in vacuum.

To remove the wires from the test racks, they are cut off as closely as possible to their points of welded attachment at the ends. The removed wires are shipped to the testing laboratory where approximately an inch is removed from each end, the ends faced in a lathe, and the length of the wire then measured with the same accuracy as that employed in the original measurement when the wire was slightly longer. For purposes of calculation, it is assumed that, if the original wire was just 42.5 in. long and the same wire returned and trimmed is just 39 in. long, the original weight of the shortened length is 39/42.5 of the weight of the 42.5-in. length.

After the length measurement is made, the wire is cleaned by immersion in a sulfate- and chloride-free solution of chromic acid (200 g. CrO_3 per liter), rinsed in running water, wiped dry, weighed in air to the nearest 0.001 g., and corrected to weight in vacuum.

Methods for Measuring Thickness of Zinc Coatings on Plain Wires:

The minimum and maximum thickness of the coating was measured on the polished metallographic specimen used for microscopic examination. This was a cross-section of the wire perpendicular to the longitudinal axis of the wire. The image was projected on the ground glass of the metallographic microscope so as to produce a linear magnification of 1000 diameters and measured with a scale graduated to $\frac{1}{16}$ in. In each case the iron-zinc alloy layers were considered as part of the coating in making the measurement of the thickness of the coating.

Methods for Mounting, Polishing, and Etching of Specimens for Photomicrographs:

Zinc-Coated Wires.—All specimens were mounted for polishing in Lucite (a transparent plastic material) except samples Nos. B-149 and B-215 which were copper plated electrolytically prior to mounting. Samples were cleaned with alcohol before mounting. A pressure of 4000 psi. was applied and the temperature raised to 120 C. in the mounting procedure. The temperature dropped to 70 C. under pressure before demounting.

After mounting, the sample was rubbed down on Nos. 1, 0, 00, and 000 emery paper. Then it was polished dry on a satin cloth-covered wheel with K5XM Aloxite brand abrasive. Polishing was continued with the wheel revolving at a very moderate rate, until previous scratches had been removed. The sample was then polished by hand on a chamois by using a "Grade A extra fine" buffing powder. Polishing was continued until scratches from the preceding step were removed in the coating only.

The Palmerton reagent (20 g. chromic acid, 1.5 g. sodium sulfate, 100 ml. distilled water) was used for etching. The specimen was rinsed in a solution of 20 g. chromic acid, 100 ml. of water after etching and then washed in a stream of tap water.

Copper-Coated Wires.—Samples of copper-coated wire were mounted in Bakelite (2000 psi. at 135 C.) and polished by hand on emery papers of decreasing abrasive grit size. From the finest emery paper, the specimen was polished wet on the broadcloth-covered wheel with alumina and finished on the automatic polisher (velvet-covered wheel) with rouge. The following etching reagent was used: 10 g. ferric chloride, 30 ml. HCl (sp. gr. 1.19), 120 ml. alcohol.

Lead-coated Wires.—Lead-coated samples were mounted in molten sulfur which was allowed to solidify in place. The grinding was done by using kerosine saturated with paraffin on the emery papers as a lubricant. Polishing was carried out on a velvet cloth wheel with a suspension of a fine buffing powder (Aloxite, Grade A) in a soap solution. A solution of 1 part glacial acetic acid, 1 part HNO_3 (sp. gr. 1.42), and 4 parts glycerol (by volume) was used for etching, the surface being lightly swabbed once with the solution and then washed in water.

Stainless Steel Wires.—The samples of stainless steel wire were mounted in Bakelite and polished for microscopic examination. After grinding the specimen down on emery papers, the polishing was carried out in two steps: first, using levigated alumina on broadcloth, and, second, finishing with rouge on a velvet cloth. Ammonium persulfate was used with an electrolytic etch. Contact was made on the wire by drilling the mounting material opposite the polished surface. The specimens were repolished and re-etched several times.

Methods for Determining Breaking Load, Tensile Strength, and Elongation of Plain Wires:

Breaking Load.—The Amsler testing machine was used in determining the tensile strength and elongation of the wire. Flat surface wedge grips were used in testing the stainless steel wire samples and Templin grips for the samples of larger gage size.

The stainless steel and the smaller gage size samples frequently broke within the grips. A wrapping of emery cloth around the portion of the sample within the grips was necessary in order to correct this difficulty. It was necessary in many instances to test ten or more specimens from the same coil of wire in order to obtain three in which the fracture occurred within the middle third of the gage length. The value reported in the table is the average of three having the fracture within the middle third.

Tensile Strength.—Two calculations were made for the tensile strength of zinc-coated samples. In one the diameter of the stripped wire was used, and in the other, the diameter of the coated wire. An average of three specimens having the fracture within the middle third is reported.

Elongation.—Elongation, to the nearest 0.01 in., was measured on a gage length of 10 in. on each specimen. The gage length had been marked on it with crayon and not with punch marks, which would have tended to localize the fracture at such points. The elongation reported is the average of three specimens having the fracture within the middle third of the gage length. The moving head of the testing machine is operated at a speed of 0.1 in. per min.

Methods of Making Wrap Tests on Plain Wires:

The wrapping test to determine the adhesion of the coating to the base metal was made by twisting the wire into a helix. The sample, after being bent sharply into a U shape, was clamped in a lathe with one arm centered and one arm projecting outward. The wire constituting this arm was then wrapped approximately fifteen turns around the centered wire with the lathe turning at a speed of 14 revolutions per minute. Just enough pressure was applied to cause a close wrap of the wire, a piece of wood being used to assist in holding the six and nine gage wire in place. The smaller size was held by hand without any other support.

Examination of the specimen was made with the unaided eye and the binocular microscope at a magnification of six diameters.

REPORT OF WIRE INSPECTION COMMITTEE ON FIELD TESTS OF WIRE AND WIRE PRODUCTS

NOTE.—Reference to the concurrently published final report of the referee analyses[1] made at the National Bureau of Standards will be helpful in certain studies of this report. The concurrent report presents detailed critical data not shown in this report, including: (1) chemical analyses of the base metal of the wires; (2) chemical analyses of the zinc coatings for impurities; (3) microstructure of the coatings (zinc, lead, and copper) and of the base metal of stainless steel specimens; and (4) wrap tests and Preece tests of the zinc coatings.

This report presents the results of the atmospheric corrosion tests on wire and wire product specimens after exposure for about two years at each of eleven locations. Table A outlines the main features of the exposure tests, that is, the locations, magnitude and nature of the specimens chiefly involved.

The extent of corrosion on specimens is being measured by the following:

1. Visual examination at the test locations either semi-annually or annually, depending on the corrosiveness of the test site atmosphere. At the time of inspection, records are made of the appearance of every wire and wire product sample at each test site. The records are

(*a*) Qualitative descriptions prior to the time of the appearance of rust or rust-resembling corrosion products; that is, the samples are noted as appearing "metallic," "gray," "brown," "black," etc.

(*b*) Quantitative estimations after the appearance of rust or rust-like corrosion products. Estimates are made of the percentage of area in each sample that has actually rusted and the percentage that is "yellowed," seemingly by iron corrosion products, but has not yet shown actual rusting of the base metal.

2. Tension tests on the unfabricated wire specimens. These are the specimens exposed in heptads, that is, seven samples taken from the same lot of wire and supposedly alike. The plan calls for removing and testing the first specimen of each heptad when it has lost 5 to 10 per cent of its strength; the seventh sample, when it has lost some 75 per cent of its strength; and the intermediate five samples when they have lost suitable proportions of their strength.

The records of progressive loss of strength of the unfabricated wire samples will afford an indication of the rate of loss of strength of the wires in the farm fence and barbed wire specimens, because wire from nearly every lot used in the fabrication of the fences and barbed wires is also under test as unfabricated wire.

3. Loss of weight tests to be made on lengths of zinc-coated wire (each about 42 in. long) carefully weighed and measured before exposure. There are 144 wires (16 alike of each of 9 wire lots) exposed at each of the locations of Pittsburgh, Sandy Hook, and State College. These wires originally carried weights of coating of 0.66 to 1.04 oz. per sq. ft. Plans call for the specimens at each location to be removed one-fourth at a time—the first quarter when they have

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[1] See p. 101.

lost a relatively small percentage of their coating; the last quarter when most of the coating has gone but before significant rusting has occurred; and the intermediate two one-quarter lots when they have lost suitable proportions of their coating. The method being used for preparing the returned specimens for weighing involves cleaning by a chromic acid solution which removes all the corrosion products of zinc but does not remove the elementary metals. Ammonium citrate has been used in a few cases on severely corroded samples to remove the iron rust, and while the weight loss tests on such samples may be reported the results are not ordinarily included in analyses of data pertaining to the losses of coating weight. The tested samples are not returned to the exposure plots.

TABLE A.—OUTLINE OF EXPOSURE TESTS.
Locations, Magnitude, and Nature of Specimens Chiefly Involved.

Exposure Sites	Approximate Number of Specimens at Each Site				
	Farm Fence[a]	Barbed Wire[a]	Unfabricated Wire[b]	7-Wire Strand	Chain-Link Fence
Pittsburgh, Pa.	None	None	120	13	20
Sandy Hook, N. J.	None	None	120	13	20
Bridgeport, Conn.	3	None	120	13	20
State College, Pa.	72	23	120	13	20
Ithaca, N. Y.	72	23	120	13	20
Lafayette, Ind.	72	23	119	13	20
Ames, Iowa	72	23	120	13	None
Manhattan, Kans.	72	23	120	13	None
College Station, Tex.	72	23	119	13	None
Davis, Calif.	72	23	114	13	20
Santa Cruz, Calif.	72	23	114	13	20
Base Metal and Coatings	Division of the 72's, 23's, 120's, 13's and 20's as Regards Base Metal and Coatings				
Uncoated steel	8	2	19	0	0
Copper-covered steel	1	1	2	0	0
Lead-coated steel	1	1	4	1	1
Corrosion-resistant steel	3	0	10	0	2
Zinc-coated steel	59	19	85 84 for 119's 79 for 114's	12	17
CHARACTERISTICS OF THE ZINC-COATED SPECIMENS					
Approximate weight of coating range, oz. per sq. ft.	0.25 to 2.75	0.25 to 2.00	0.25 to 3.00	0.70 to 2.50	0.25 to 2.90
Gages involved	14½	....	14½	....	....
	12½	12½	12½	....	....
	11	....	11	11	....
	9	....	9	....	9
	....	....	6	....	6

[a] In the fabrication of each specimen of barbed wire and farm fence, wire of a known lot number was used. Wire from each of these known lots (with a few exceptions) is also under test as unfabricated wire specimens.

[b] Also referred to as tensile strength specimens. The numbers shown in this column are the number of wire lots; actually there are 7 specimens of each wire lot exposed at each location, that is, 840 (or 833, or 798) specimens. In addition to these some 800 wires at each location, there are 144 additional "Loss of Weight" specimens at Pittsburgh, at Sandy Hook, and at State College.

Inspection Procedures and Methods of Testing Removed Wires:

Inspections at Bridgeport, Sandy Hook, Pittsburgh, and State College are made twice a year by a travelling committee, the visits being simultaneous with those of the hardware and sheet inspections of Subcommittee VIII of Committee A-5. The inspections at the other seven sites are made only once a year (usually in October) because none of these locations has an atmosphere sufficiently corrosive to justify semiannual inspections. Although the State College specimens might also be inspected only once a year, this location has thus far been visited semi-annually to afford illustrative information on the rate of corrosion at the other seven rural sites. These latter sites now appear to resemble State College in the corrosiveness of their atmospheres.

The annual inspections at the seven test sites established at Universities in 1936 are made by the resident university people in charge of the test plots. At the present time the men accepting these responsibilities at the various locations are:

J. D. Long	Davis, Calif., and Santa Cruz, Calif.
H. P. Smith	College Station, Tex.
Henry Giese	Ames, Iowa
F. C. Fenton	Manhattan, Kans.
I. D. Mayer	Lafayette, Ind.
B. A. Jennings	Ithaca, N. Y.

In order to help these men orient their judgment so that they will appraise corroding specimens in a manner similar to the veteran inspectors of Subcommittee VIII of Committee A-5, written instructions were sent to them. Also, a meeting was arranged at Lafayette, Ind., on December 3, 1937, at a time when a convention of the American Society of Agricultural Engineers was drawing to a close in Chicago, and most of the men were available to go to nearby Lafayette. At this meeting, several hours were spent in inspecting samples together in the interest of developing a uniform understanding.

Up to April 1, 1939, inspections and removal of tensile strength specimens have been made as shown in Table B. The tensile strength specimens are pieces of straight wire 42 in. long, positioned horizontally on supporting frames. Twenty to thirty of these wires arranged like the bars of a grating are attached to each frame by welding at their ends.

Wire Removal Procedures:

A scheme has been devised for removing the tensile specimens from the frame and shipping them to a testing laboratory. The scheme involves cutting the wires off the frames, putting each removed wire in a $\frac{3}{8}$-in. diameter cardboard tube, and enclosing several of these small tubes in a mailing tube for shipment. Before any wire is cut off, an adhesive tape label is attached to it which identifies it as regards test site, gage of the wire, and weight and nature of its coating (if any).

TABLE B.—INSPECTIONS AND REMOVALS OF TENSILE STRENGTH SPECIMENS UP TO APRIL 1, 1939.

Location	Inspection Date	Exposure, yr.	Number of Wires Removed			Weights of Zinc Coating on Wires Removed, oz. per sq. ft.
			Bare Steel	Lead Coated	Zinc Coated	
Pittsburgh, Pa.[a]	7/37	0.68	0	0	0	....
	10/37	0.97	0	0	0	....
	4/38	1.48	19	4	36	0.25 to 0.55
	10/38	1.94	19	0	42	0.25 to 0.78
Sandy Hook, N. J.	10/37	0.93	0	0	0	....
	4/38	1.44	19	4	19	0.25 to 0.40
	10/38	1.90	11	0	3	0.25
Bridgeport, Conn.[a]	7/37	0.66	0	0	0	....
	4/38	1.36	19	4	13	0.25 to 0.30
	10/38	1.90	7	0	6	0.25
State College, Pa.	10/37	0.84	0	0	0	....
	4/38	1.30	19	4	0	....
	10/38	1.84	3	0	0	....

Inspections were made in 1937 and 1938 in the fall or early winter at the following:

Location	Exposure, Yr.		Wire Removals
Ithaca, N. Y.	1.01	1.90	No wires were taken at the first inspection. At the second inspection 19 bare steel wires were removed at each location. No zinc- or lead-coated wires were taken.
Lafayette, Ind.	0.99	1.99	
Ames, Iowa	0.91	2.12	
Manhattan, Kans.	0.89	1.86	
College Station, Tex.	0.83	1.83	
Davis, Calif.	0.83	1.94	
Santa Cruz, Calif.	0.83	1.94	

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[a] These first inspections at Pittsburgh and at Bridgeport were orienting inspections (made shortly after organization of the committee) undertaken to assist in developing methods.

The schedule of removing specimens for tensile testing was not prearranged in the planning of the tests. The removal periods have to be worked out to fit the condition of corrosion at the different sites. Thus removals at relatively short intervals are required for Pittsburgh but not for certain rural sites. The dates of first removals have to be judged largely from the appearance of the wires—ordinarily the first inspection date after the initial appearance of rust. The succeeding removal dates are judged from records already accumulated for any heptad.

Laboratory Methods of Examining Wires:

Breaking load and elongation tests of the tensile specimens are made with an Amsler testing machine. Flat surface wedge grips are used in testing the stainless steel wire samples, and Templin grips are used for the samples of larger gage size. Certain wires tend to break within the grips. A wrapping of emery cloth around the portion of the sample within the grips is employed to minimize this difficulty.

Elongation, to the nearest 0.01 in., is measured on a gage length of 10 in. on each specimen. A 10-in. gage length is marked on the wire with crayon and not with punch marks, which would tend to localize the fracture at such points.

In making tensile and elongation tests of wires removed from the test racks, each wire is cut into three pieces approximately 13 in. long. The results reported are the average of the three tests.

The specimens for loss of weight tests were weighed and carefully measured at 68 C. The diameter measurements were accurate to 0.0005 in. The length measurements were accurate to 0.002 in. for 6, 9, 11, and $12\frac{1}{2}$ gage wires; and to 0.003 in. for No. $14\frac{1}{2}$ gage wires. All wires were weighed in air to the nearest 0.001 g. and corrected to weight in vacuum.

To remove the wires from the test racks, they are cut off as closely as possible to their points of welded attachment at the ends. The removed wires are shipped to the testing laboratory where approximately an inch is removed from each end, the ends faced in a lathe, and the length of the wire then measured with the same accuracy as that employed in the original measurement when the wire was slightly longer. For purposes of calculation, it is assumed that if the original wire was just 42.5 in. long and the same wire returned and trimmed is just 39 in. long, the original weight of the shortened length was 39/42.5 of the weight of the 42.5-in. length.

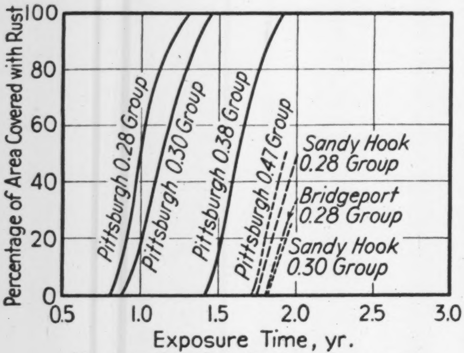
After the length measurement is made, the wire is cleaned by immersion in a sulfate and chloride-free solution of chromic acid (200 g. per liter), rinsed in running water, wiped dry, weighed in air to the nearest 0.001 g. and corrected to weight in vacuum.

Findings from Visual Examination for Corrosion at the Test Plots:

Tables I, II, III, IV, and V show the detailed results of inspections for corrosion respectively of unfabricated wire, barbed wire, farm field fence, chain-link fence, and strand. At the time of the present report, the results of inspections of the unfabricated wire provide the most indicative information because they comprise the greatest variety of samples and are under test at every location. (Farm fences also provide a wide range of samples but are not included in the most corrosive test plots—Pittsburgh, Sandy Hook, and Bridgeport.) The following facts and indications are shown by the visual inspections to date:

1. *Zinc-Coated Specimens.*—Extensive rusting has occurred at Pittsburgh in two years, and some at Sandy Hook and Bridgeport. The wires rusted at Pittsburgh involve those carrying coatings up to about 0.8 oz. per sq. ft.; at Sandy

Hook, 0.45 oz. per sq. ft. (and lighter) coated samples; and at Bridgeport, 0.35 oz. and lighter coated samples. The extent of rusting at these three locations is shown in the Progressive Development of Rust curves of Fig. 1, and in the information listed under the figure. These curves and information are a condensed graphic exposition of data listed in detail in Table I.



(Average time for samples of any group to rust to the extent indicated)

FIG. 1.—Progressive Development of Rust on Zinc Coated Unfabricated Wires.

Groups, in which some (but not all) of the samples are rusted, not included in Fig. 1 are:

Nominal-Coating Group, oz. per sq. ft.	Avg. Coating, oz. per sq. ft.	Number of Samples		Condition as Compared to Above Curves
		Total	Rusted	
Pittsburgh Groups				
0.50 to 0.60	0.56	5	4	About the same or slightly more rusted than 0.47 oz. per sq. ft. group.
0.60 to 0.70	0.65	12	6	Less rusted than any group shown.
0.70 to 0.85	0.75	10	6	About the same as Sandy Hook 0.30 oz. per sq. ft. group.
Sandy Hook Group				
0.35 to 0.45	0.38	7	6	Less rusted than any group shown above.
Bridgeport Group				
0.25 to 0.35	0.30	8	3	Less rusted than any group shown above.

All other groups at all locations are free from rust.

The method used to derive the curves of Fig. 1 is the following:

Consider one group at a time, for example the Pittsburgh 0.28 oz. per sq. ft., group which contains six specimens.

Examine the individual records of each of the six samples, and for each specimen write down the length of time required to rust to the extents of 3, 10, 25, 50, 75, and 100 per cent. This involves interpolation between the inspection periods.

Average the estimated times to rust 3, 10, 25, etc., per cent, and plot curves from these averaged figures.

This method is somewhat different than the one which has generally been used in the sheet inspection reports of Committee A-5. The new method produces steeper curves and provides a truer engineering picture of the average performance of specimens.

In the cases of zinc-coated wires which have not yet developed rust—even those in the same weight of coating classes—there are characteristic tendencies for some to become grayed in appearance after a relatively short exposure and for others to retain a metallic or bright appearance. Reference to the micrographs in the concurrently published report of the referee analyses indicates that generally: those remaining bright have no zinc-iron alloy layers in their coating, or else have these layers well covered with surface layers of zinc; those becoming gray early have little or no surface zinc layer. This tendency to become gray early should not be interpreted as a forecast of early development of rust.

2. *Copper-Covered Specimens.*—No rusting of these wires has occurred at any location in two years.

3. *Lead-Coated Wires.*—All of the lead-coated wires at all locations have developed a rusted or rust-like appearance. The discoloring iron corrosion products have been reported in all cases as appearing in patterns of speckles, seemingly at pinhole points in the coat-

ings. In field inspections of these lead-coated wires, it is difficult to judge the extent of actual corrosion of the base metal. This is particularly true if a wire has a rough surface which has become discolored by the spread of the iron corrosion products originating at pinholes. A better seasoned judgment on

TABLE C.—A LISTING TO ILLUSTRATE CERTAIN PECULIARITIES AND TRENDS OF THE TENSILE STRENGTH DATA.

Lots of zinc-coated steel wire for which two removals have been made.

Caption Abbreviations:

$S_0(a)$ —First tensile strength test of unexposed specimens.
$S_0(b)$ —Second tensile strength test of unexposed specimens.
S_0 —Average of $S_0(a)$ and $S_0(b)$.
S_1 —Tensile strength of specimen removed after about 1½ yr.
S_2 —Tensile strength of specimen removed after about 2 yr.
R_1 —Per cent of rusted area on specimen removed after about 1½ yr.
R_2 —Per cent of rusted area on specimen removed after about 2 yr.

Wire Lot	Breaking Load, lb.				Change, per cent		Per Cent Rusted	
	$S_0(a)$	$S_0(b)$	S_1	S_2	$\frac{S_1 - S_0}{S_0}$	$\frac{S_2 - S_0}{S_0}$	R_1	R_2
1. FIRST REMOVALS UNRUSTED; SECOND REMOVALS USUALLY PARTLY RUSTED.								
1.1 Pittsburgh removals								
No. 430	780	....	790	815	+1.3	+4.5	0	0
No. 227	1640	....	1590	1570	−3.0	−4.3	0	2
No. 226	1150	....	1110	1170	−3.5	+1.7	0	6
No. 225	1650	....	1630	1635	−1.2	−0.9	0	7
No. 329	720	....	710	750	−1.4	+4.2	0	13
No. 327	1160	....	1120	1135	−3.5	−2.3	0	28
No. 325	730	....	720	745	−1.4	+2.1	0	51
No. 521	270	....	280	285	+3.7	+5.5	0	56
No. 127	2540	....	2610	2560	+2.8	+0.8	0	72
No. 421	470	....	450	455	−4.3	−3.2	0	87
No. 432	510	....	520	460	+2.0	−9.8	0	97
No. 431	880	....	820	780	−6.8	−11.4	0	98
No. 228	1080	....	1080	1085	0	+0.5	0	100
1.2 Sandy Hook removals								
No. 511	280	290	250	290	−12.3	+1.7	0	30
No. 510	500	500	490	510	−2.0	+2.0	0	33
No. 512	320	330	290	310	+3.1	−3.1	0	95
1.3 Bridgeport removals								
No. 411	630	600	600	685	−2.4	+11.4	0	1
No. 412	840	820	830	835	0	+0.6	0	4
No. 510	500	500	510	530	+2.0	+6.0	0	5
No. 511	280	290	260	290	+8.8	+1.8	0	13
No. 512	320	330	300	320	−7.8	−1.5	0	16
No. 410	570	575	550	600	−4.0	−4.7	0	21
2. FIRST REMOVAL PARTLY RUSTED; SECOND 100 PER CENT RUSTED (ALL FROM PITTSBURGH)								
No. 125	1840	....	1840	1785	0	−3.0	1	100
No. 317	780	805	....	750	....	−5.6	2	100
No. 422	500	....	460	475	−8.0	−5.0	2	100
No. 326	700	....	670	610	−4.3	−12.9	8	100
No. 216	1630	....	1600	1530	−1.8	−6.1	52	100
No. 412	840	820	790	760	−4.8	−8.5	66	100
No. 423	400	....	370	370	−17.5	−17.5	66	100
No. 316	1110	1160	1110	1070	−2.2	−5.7	81	100
No. 217	1080	1080	1060	1080	−1.9	0	94	100
No. 115	2690	2740	2650	2505	−0.6	−5.9	97	100
3. BOTH REMOVALS 100 PER CENT RUSTED (ALL FROM PITTSBURGH)								
No. 511	280	290	210	205	−26.3	−28.1	100	100
No. 512	320	330	240	235	−26.1	−27.7	100	100
No. 410	570	575	470	465	−18.0	−18.8	100	100
No 411	630	600	560	555	−7.3	−9.7	100	100
No. 315	890	910	770	820	−14.4	−9.0	100	100
No. 215	1200	1220	1100	1100	−9.9	−9.9	100	100
No. 117	2230	2200	2090	2090	−5.7	−5.7	100	100

these lead-coated wires will be provided by future tests on the tensile strength of removed specimens.

4. *Uncoated Corrosion-Resistant Steel Wires.*—No significant corrosion of these wires has developed at any location in two years. However, some of the 12 to 14 per cent chromium wires have developed superficial yellow or rust discolorations. The 18 per cent chromium, 8 per cent nickel wires have generally remained bright or metallic colored.

TABLE D.—LOSS OF STRENGTH SHOWN BY EXPOSED UNCOATED STEEL WIRES.
An analysis of certain significant data shown in Table VI.

Gage	Wire Lot	Pittsburgh, Pa. Exposure		Sandy Hook, N. J. Exposure		Bridgeport, Conn. Exposure		State College, Pa. Exposure		Original Breaking Load, lb.
		1.48 yr.	1.94 yr.	1.44 yr.	1.90 yr.	1.45 yr.	1.91 yr.	1.30 yr.	1.76 yr.	
1. COPPER-BEARING SPECIMENS										
1.1 Loss of strength, lb.										
14.5	No. 506	170	185	130	130	110	90	90	70	520
	No. 507	185	215	135	155	105	105	95	85	595
12.5	No. 405	115	115	95	75	85	65	65	....	485
	No. 406	100	100	90	70	70	40	60	....	470
11	No. 305	215	165	135	160	95	....	95	....	1085
	No. 306	120	105	100	85	50	....	60	....	710
9	No. 205	180	125	140	....	90	....	100	....	1110
	No. 206	230	245	200	....	150	....	130	....	1480
6	No. 102	285	290	245	....	235	....	155	....	2095
	No. 106	90	195	130	....	100	....	40	....	2400
1.2 Loss of strength, per cent per year										
14.5	....	21.5	18.5	16.6	13.4	13.1	9.2	12.7	7.7	....
12.5	....	15.2	11.5	13.5	7.9	10.9	5.8	10.0	....	....
11	....	12.5	7.7	9.0	7.1	5.5	....	6.5	....	....
9	....	10.8	7.2	9.4	....	6.2	....	6.9	....	....
6	....	6.1	5.7	5.9	....	5.2	....	3.5	....	....
1.3 Calculated Diameter Decreases, Accounting for Above Losses of Strength, in. per yr.										
14.5	....	0.0087	0.0074	0.0065	0.0052	0.0050	0.0035	0.0049	0.0030	....
12.5	....	0.0074	0.0056	0.0066	0.0038	0.0053	0.0027	0.0048	....	....
11	....	0.0078	0.0048	0.0055	0.0043	0.0033	....	0.0040	....	....
9	....	0.0082	0.0054	0.0072	....	0.0046	....	0.0052	....	....
6	....	0.0060	0.0056	0.0058	....	0.0050	....	0.0034	....	....
2. LOW-COPPER CONTENT SPECIMENS										
2.1 Loss of strength, lb.										
14.5	No. 501	180	195	110	120	80	115	60	55	500
12.5	No. 400	120	110	90	70	80	50	60	....	480
	No. 401	130	115	80	70	70	50	50	....	450
11	No. 300	150	135	100	90	80	....	70	....	740
	No. 302	280	280	110	180	190	....	120	....	1100
9	No 200	215	200	155	....	125	....	75	....	1045
	No. 202	310	295	140	....	190	....	40	....	1640
6	No. 101	315	310	175	....	185	....	125	....	2315
	No. 105	360	375	260	....	230	....	180	....	2760
2.2 Loss of strength, per cent per year										
14.5	....	24.2	20.0	15.3	12.6	10.9	12.0	9.2	6.3	....
12.5	....	18.2	12.4	12.8	8.2	11.4	5.5	9.2	....	....
11	....	15.2	11.1	11.5	7.4	9.6	....	7.7	....	....
9	....	13.5	9.5	8.3	....	8.3	....	3.5	....	....
6	....	9.1	7.2	5.9	....	5.5	....	4.6	....	....
2.3 Calculated Diameter Decreases, Accounting for Above Losses of Strength, in. per yr.										
14.5	....	0.0096	0.0080	0.0060	0.0049	0.0042	0.0047	0.0036	0.0024	....
12.5	....	0.0090	0.0060	0.0062	0.0038	0.0055	0.0026	0.0044	....	....
11	....	0.0095	0.0068	0.0071	0.0046	0.0059	....	0.0047	....	....
9	....	0.0104	0.0072	0.0062	....	0.0062	....	0.0026	....	....
6	....	0.0090	0.0071	0.0058	....	0.0054	....	0.0045	....	....

Findings from Specimens Removed for Tension Tests:

Table VI shows the detailed results of the tension tests on all removed wire specimens. Before listing the indications afforded by these data, certain peculiarities may be cited which have a bearing on the interpretation of the data.

Peculiarities of the Tensile Strength Data:

1. A few bare wires removed from each of the locations: Manhattan, Kans.; College Station, Tex.; Davis, Calif.; and Santa Cruz, Calif., after exposure of two years were found to be a few per cent stronger than their companion samples which had been tested in the laboratory and not exposed. This condition did not obtain for any bare wire specimens exposed at any of the other seven test locations.

2. In the majority of cases of bare wire and zinc-coated wire lots, when two sets of removals have been made, the specimen of the second removal was found to be stronger than that of the first. Table C segregates all the cases involving two removals of lots of zinc-coated wire (compare columns S_1 and S_2); and Table D shows the double removals of bare wire (compare the paired columns for each location under paragraphs 1.1 and 2.1).

When the above peculiarities were noted, an effort was made to discover their cause and significance. Possible explanations are:

(*a*) Chance variation. Tensile strength tests on individual lengths of wire cut from the same coil may vary 5, or even 10 per cent. A recently removed specimen may test stronger than was expected; but by chance, it may have been stronger than its earlier tested companion samples. It may have lost some strength but not enough to overbalance the amount by which it was originally stronger.

(*b*) A small actual gain in strength due to a natural aging action.

To discover if the strength changes were due to a natural aging action, samples of 32 wire lots were retested in April, 1939, the test specimens being cut from the same coils as those furnishing the specimens used for the original strength tests in November 1937. (The 1937 testing date was approximately 15 months after fabrication of the wires.) Some of these results are shown in Table C in the columns headed $S_0(a)$ and $S_0(b)$; other results may be found in Table VI. Following is a résumé of the comparison of the two sets of tests:

6 wires showed no change.
7 wires showed a loss—average: 2.0 per cent.
19 wires showed a gain—average: 3.0 per cent.

Only 2 wires of the 32 showed changes of more than 5 per cent, one a gain of 6.9 per cent, and the other a gain of 5.3 per cent.

(*c*) A small actual gain in strength due to work hardening. This might have been caused by the straightening operation used to prepare the specimens for welding onto the test racks (reported to have been a very mild operation); or it might have been caused by vibration of the specimens on the racks, or by their expansion or contraction due to temperature changes.

(*d*) Position of exposure on the test racks. A possible explanation of why the second set of removals is stronger than expected may be that it is a result of their position of exposure on the test racks. All of the wires in the first removals were cut from frames on the west sides of racks at Pittsburgh and at Bridgeport, and from the east sides at Sandy Hook; in the second set, they were taken from the opposite sides of the racks at each location. There is evidence that there is generally a little more rapid tendency for corrosion on the west side of the test racks than on the east, except in the case of Sandy Hook where the east side corrosion tends to lead the west side action. This possible explanation is offered in this report for its suggestive value of future observations to be made.

The above discussed peculiarities of some removed specimens testing stronger than expected do not appear to be very serious or disconcerting as regards the general interpretation of present and future test results. They merely indicate the need for a little conservatism in using the present available results for making estimates of how long wire specimens will be serviceable after their coatings are gone.

TABLE E.—LOSS OF STRENGTH SHOWN BY ZINC-COATED STEEL WIRES EXPOSED AT PITTSBURGH, PA

An analysis of the data shown in Table VI for coatings of 0.20 to 0.35 oz. per sq. ft. at Pittsburgh.

Wire Lot	Exposure 1.48 yr.		Exposure 1.94 yr.		Original Breaking Load, lb.	Wire Lot	Exposure 1.48 yr.		Exposure 1.94 yr.		Original Breaking Load, lb.
	Time, yr.[a]	Loss of Strength, lb.	Time, yr.[a]	Loss of Strength, lb.			Time, yr.[a]	Loss of Strength, lb.	Time, yr.[a]	Loss of Strength, lb.	
No. 510	0.28[b]	0	0.74	4	500	No. 316	0.28[b]	25	0.74	65	1135
No. 511	0.88	75	1.34	80	285	No. 317	....	....	0.49	45	795
No. 512	0.98	85	1.44	90	325	No. 215	0.88	110	1.34	110	1210
No. 410	0.83	105	1.29	110	575	No 216	0.18	30	0.64	100	1630
No. 411	0.63	55	1.09	60	615	No. 217	0.43	20	0.89	0	1080
No. 412	0.23	40	0.69	70	830	No 115	0.83	65	1.39	210	2715
No. 315	1.03	130	1.49	80	900	No. 117	0.73	125	1.29	125	2215

	X—Loss of Strength, per cent per year since rusting began		Gage		Y—Calculated Annual Diameter Decreases, Accounting for Observed Strength Losses, in. per yr. since rusting began		Gage
No. 500's	19.4	18.0	14.5	No. 500's	0.0080	0.0074	14.5
No. 400's	20.5	12.0	12.5	No. 400's	0.0089	0.0060	12.5
No. 300's	10.9	8.4	11	No. 300's	0.0067	0.0051	11
No. 200's	8.2	5.4	9	No. 200's	0.0061	0.0041	9
No. 100's	5.3	5.3	6	No. 100's	0.0052	0.0056	6

[a] Time, first rust to removal date.

[b] The dates of first rust are estimated by interpolation between the inspection date when rust first appeared and the preceding inspection six months earlier. These estimates were made to the nearest 0.05 year. The odd figures in the above table are the result of subtractions from the exposure figures of 1.48 and 1.94 year.

Indicated Trends of the Tensile Strength Data:

1. Ordinarily zinc-coated wires do not show significant losses of strength until after rusting of the base metal has started. (Compare the adjacent columns under "Percentage Change" of paragraphs 1 and 2 of Table C.) Consequently, it should be a reasonable procedure to intercompare the strength losses per year shown by the zinc-coated wire after base metal rusting starts with the strength loss per year shown by the uncoated steel wires. Direct comparison, of course, can be made only between wires of the same gage exposed at the same location.

The method chosen for these intercomparisons in Tables D and E is the showing of calculated diameter decreases (in inches per year) necessary to account for the losses of strength found by test. These annual diameter decreases have been calculated as follows:

$$\text{Diameter decrease} = \frac{D(1 - \sqrt{\text{Sr}})}{t}$$

where D = original wire diameter,

t = years since the beginning of rust (base wires assumed to start rusting immediately after exposure), and

Sr = percentage of strength remaining in the specimen at the time of removal.

If it could be assumed that any sample would show the same continued diameter decrease per year, its service life could be calculated from a simple ratio. Thus, the time for a wire to lose half its strength would be given by dividing 0.293*D* by the annual diameter decrease figure.

Using the annual diameter decrease comparison method, the data in Tables D and E show the trends outlined below.

2. The order of corrosiveness of test locations (most severe to mildest) is: Pittsburgh, Sandy Hook, Bridgeport, State College. From the data at hand, all of the other seven locations seem milder than State College, but definite ratings are not yet certain.

3. The copper-bearing uncoated wires are corroding less rapidly than the low-copper content ones at Pittsburgh. Thus far the differences do not appear significant at the other locations. (Compare paragraphs 1.3 and 2.3 of Table D.)

4. Thus far there is no very clear-cut indication that the lighter gage uncoated wires are being penetrated more rapidly than the heavy gage ones, although the data for the Pittsburgh removals might be so interpreted. (See paragraphs 1.3 and 2.3 of Table D, and Y of Table E.)

5. The annual loss of strength (as well as the calculated diameter decrease) of the wires at Pittsburgh carrying the lightest zinc coatings is about the same as that for the bare wires at Pittsburgh. In drawing this comparison, the date of initial rusting of the coated samples has been estimated and the changes figured as annual effects since this date. (Compare the data of paragraphs 1.2, 1.3, 2.2, and 2.3 of Table D with **X** and Y of Table E.)

Findings from Weight Loss Specimens:

Reference to Table VII will show the following for the first set of weight loss specimens removed:

1. There is a tendency for the wires of lighter gages to lose coating somewhat faster than the wires in the heavier gages.
2. There is no definite indication to date of a difference in the rates of loss of groups A, B, and C. By reference to the concurrently published report of the Wire Test Committee, the wires within group A (or B, or C) will be found to be closely alike as regards base metal composition and coating characteristics.
3. There appears to be no significant difference in corrosion rates of wires exposed in the east side of the test racks, as compared to those exposed on the west side.

Respectfully submitted on behalf of the Wire Test Inspection Committee,

C. D. HOCKER,
Chairman.

TABLE I.—REPORT OF INSPECTIONS OF UNFABRICATED WIRE SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic, G = gray, Y = yellowed, or rust stained, but not showing actual rough rust of base metal. (In cases of zinc coatings, the G and Y conditions are characteristic states of corrosion of zinc iron alloys in the coatings.) R = rust of base metal. PHR, PHY = rust or yellowed in pinholes. B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance (usually apply to wires other than zinc-coated ones). D = dark (dirt or soot) to the exclusion of a better observation. Cr = yellow from chromate treatment. MG = intermediate between M and G. GY predominately gray but showing indication of Y. Figures (as 5, 20, 50, 100) are percentages.

Coating Group	Zinc Coating, oz. per sq.ft. of surface[a]	Wire Lot	Pittsburgh (Brunot Island), Pa.				Sandy Hook, N. J.			Bridgeport, Conn.			State College, Pa.		
			0.68 yr.	0.97 yr.	1.48 yr.	1.94 yr.	0.93 yr.	1.44 yr.	1.90 yr.	0.66 yr.	1.45 yr.	1.90 yr.	0.84 yr.	1.30 yr.	1.76 yr.
0.20 to 0.30, Avg. 0.28	0.27	No. 512	49R	2Y 98R	100R	100R	G	GY	5Y 95R	G	G	40Y 60R	G	G	G
	0.30	No. 410	GY 7R	13Y 87R	100R	100R	G	GY	6Y 20R	G	G	20Y 21R	G	G	G
	0.28	No. 411	G	10Y 22R	100R	100R	G	GY	GY 9R	G	G	G 1R	G	G	G
	0.29	No. 510	G	G	25Y 75R	100R	G	GY	67Y 33R	G	G	45Y 5R	G	G	G
	0.29	No. 412	G	G	24Y 66R	100R	G	GY	GY 13R	G	G	10Y 4R	G	G	G
	0.24	No. 511	18R	3Y 97R	100R	100R	G	GY	70Y 30R	G	G	20Y 13R	G	G	G
		Avg. per cent R	12R	51R	90R	100R			33R			17R			
0.25 to 0.35, Avg. 0.30	0.25	No. 315	72R	100R	100R	100R	G	GY	28Y 72R	G	G	40Y 31R	G	G	G
	0.28	No. 215	29R	5Y 95R	100R	100R	G	G	50Y 16R	G	G	35Y 7R	G	G	G
	0.27	No. 117	1R	20Y 31R	100R	100R	G	G	50Y 6R	G	G	G	G	G	G
	0.38	No. 317	G	G	98Y 2R	100R	G	GY	GY 1R	G	G	G	G	G	G
	0.36	No. 217	G	G	6Y 94R	100R	G	GY	50Y 6R	G	G	G	G	G	G
	0.32	No. 316	G	G	19Y 81R	100R	G	GY	93Y 7R	G	G	G	G	G	G
	0.30	No. 216	G	G	13Y 52R	100R	G	GY	50Y 4R	G	G	G	G	G	G
	0.25	No. 115	5R	10Y 53R	3Y 97R	100R	G	GY	64Y 36R	G	G	15Y 36R	G	G	G
		Avg. per cent R	13R	35R	78R	100R			18R			9R			
0.35 to 0.45, Avg. 0.38	0.36	No. 520	G	G	22Y 78R	100R	G	GY	93Y 7R	G	G	G	G	G	G
	0.35	No. 422	G	G	30Y 2R	100R	G	GY	89Y 11R	G	G	G	G	G	G
	0.31	No. 423	G	G	14Y 66R	100R	G	GY	88Y 12R	G	G	G	G	G	G
	0.44	No. 522	G	G	40Y 6R	100R	G	GY	93Y 7R	G	G	G	G	G	G
	0.37	No. 282	G	G	20Y 2R	100R	G	GY	GY	G	G	G	G	G	G
	0.38	No. 521	G	G	GY	44Y 56R	G	GY	93Y 7R	G	G	G	G	G	G
	0.47	No. 421	G	G	G	13Y 87R	G	GY	86Y 14R	G	G	G	G	G	G
		Avg. per cent R			22R	92R			8R						
0.45 to 0.55, Avg. 0.47	0.44	No. 325	G	G	G	49Y 51R	G	GY	Y	G	G	G	G	G	G
	0.50	No. 228	G	G	G	100R	G	GY	Y	G	G	G	G	G	G
	0.54	No. 329	G	G	G	87Y 13R	G	GY	Y	G	G	G	G	G	G
	0.52	No. 227	G	G	G	30Y 2R	G	GY	Y	G	G	G	G	G	G
	0.41	No. 125	G	G	27Y 1R	100R	G	GY	GY	G	G	G	G	G	G
	0.54	No. 127	G	G	G	28Y 72R	G	GY	GY	G	G	G	G	G	G
	0.38	No. 326	G	G	27Y 8R	100R	G	G	GY	MG	G	G	G	G	G
	0.45	No. 226	G	G	G	50Y 6R	G	G	GY	G	G	G	G	G	G
	0.47	No. 327	G	G	G	72Y 28R	G	GY	Y	G	G	G	G	G	G
	0.45	No. 225	G	G	G	10Y 7R	G	GY	Y	G	G	G	G	G	G
		Avg. per cent R			1R	48R									
0.50 to 0.60, Avg. 0.56	0.61	No. 530	MG	M	10Y 82R	100R	G	MG	MG	M	MG	MG	MG	MG	MG
	0.57	No. 432	M	M	MG	3Y 97R	G	MG	MG	M	M	MG	MG	MG	MG
	0.60	No. 531	G	G	45Y 22R	100R	G	MG	MG	M	G	G	MG	MG	MG
	0.48	No. 431	G	G	G	2Y 98R	G	G	GY	G	G	G	G	G	G
	0.54	No. 430	G	G	G	GY	G	G	GY	G	G	G	G	G	G
		Avg. per cent R			21R	79R									

0.60 to 0.70, Avg. 0.65	0.69	No. 338	M	M	MG	MG	G	MG	MG	M	M	MG	MG	MG	MG
	0.68	No. 236	MG	M	MG	MG	G	M	MG	M	M	MG	MG	MG	MG
	0.61	No. 335	G	G	G	9Y 91R	G	G	G	MG	G	G	MG	MG	MG
	0.63	No. 237	MG	MG	G	GY 13R	G	MG	MG	M	MG	G	MG	MG	MG
	0.74	No. 135	G	G	G	GY	G	G	G	MG	MG	G	MG	MG	MG
	0.57	No. 337	G	G	G	GY 1R	G	GY	GY	G	G	G	G	G	G
	0.67	No. 235	G	G	G	GY 1R	G	GY	GY	G	G	G	G	G	G
	0.65	No. 239	G	G	G	GY	G	GY	GY	G	G	G	G	G	G
	0.67	No. 138	G	G	G	GY 1R	G	GY	GY	G	G	G	G	G	G
	0.64	No. 139	G	G	G	GY 6R	G	GY	GY	G	G	G	G	G	G
	0.66	No. 336	G	G	G	GY	G	GY	GY	G	G	G	G	G	G
	0.60	No. 238	G	G	G	GY 1R	G	GY	GY	G	G	G	G	G	G
		Avg. per cent R...				9R									
0.70 to 0.85, Avg. 0.75[a]	0.70	No. 540	MG	M	MG	70Y 24R	G	M	MG	M	MG	G	MG	MG	MG
	0.72	No. 442	MG	M	MG	MG	G	MG	MG	M	M	MG	MG	MG	MG
	0.79	No. 543	G	MG	G	20Y 20R	G	MG	MG	M	MG	G	MG	MG	MG
	0.78	No. 441	G	MG	G	10Y 8R	G	MG	MG	MG	G	G	MG	MG	MG
	0.70	No. 542	G	G	G	4Y 96R	G	G	MG	MG	G	G	MG	MG	MG
	0.74	No. 443	G	MG	G	10Y 14R	G	MG	MG	MG	G	G	MG	MG	MG
	0.74	No. 495	G	MG	G	GY 2R	G	MG	MG	Cr	Cr	Cr	Cr	Cr	Cr
	0.76	No. 541	G	G	G	GY	G	GY	GY	G	G	G	G	G	G
	0.76	No. 440	G	G	G	GY	G	GY	GY	G	G	G	G	G	G
	0.87	No. 444	G	G	G	GY	G	GY	GY	G	G	G	G	G	G
		Avg. per cent R...				16R									
0.80 to 1.00, Avg. 0.88	1.05	No. 348	MG	M	MG	MG	G	MG	MG	M	M	MG	MG	MG	MG
	0.81	No. 248	M	M	MG	MG	G	MG	MG	M	M	MG	MG	MG	MG
	0.88	No. 347	MG	MG	G	GY	G	MG	MG	MG	G	G	MG	MG	MG
	0.95	No. 246	MG	MG	G	G	G	MG	G	M	MG	MG	MG	MG	MG
	0.88	No. 346	G	G	G	GY	G	G	MG	MG	G—	G	MG	MG	MG
	0.81	No. 245	G	G	G	GY	G	G	G	M	G	G	MG	MG	MG
	0.81	No. 296	G	G	G	G	G	Cr	Cr	Cr	Cr	Cr	Cr	Cr	Cr
	0.90	No. 148	G	MG	G	G	G	G	G	M	MG	G	MG	MG	MG
	0.85	No. 149	MG	MG	G	G	G	MG	MG	M	MG	MG	MG	MG	MG
	0.84	No. 345	G	G	G	G	G	GY	GY	G	G	G	G	G	G
	0.96	No. 247	G	G	G	G	G	GY	GY	G	G	G	MG	G	G
Avg. 1.28	1.35	No. 800	G	MG	G	G	MG	MG	MG	M	MG	G	MG	MG	MG
	1.20	No. 801	G	MG	G	G	MG	MG	MG	M	MG	G	MG	MG	MG
1.60 to 1.80, Avg. 1.76	2.08	No. 552	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.83	No. 451	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.75	No. 350	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.69	No. 252	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.65	No. 351	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.76	No. 250	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.69	No. 551	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.50	No. 450	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.75	No. 352	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.86	No. 251	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
	1.86	No. 151	MG	M	MG	MG	MG	MG	MG	M	MG	MG	MG	M	MG
Heavy Avg. 2.89	2.80	No. 397	MG	M	MG	MG	MG	MG	MG	M	M	MG	MG	M	MG
	2.72	No. 298	MG	M	MG	MG	MG	MG	MG	M	M	MG	MG	M	MG
	3.00	No. 299	MG	M	MG	MG	MG	MG	MG	M	M	MG	MG	M	MG

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[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

TABLE I.—*Continued.*

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic, G = gray, Y = yellowed, or rust stained, but not showing actual rough rust of base metal. R = rust of base metal. PHR, PHY = rust or yellowed in pinholes. B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance, D = dark (dirt or soot) to the exclusion of a better observation. Cr = yellow from chromate treatment. MG = intermediate between M and G. GY predominately gray but showing indication of Y.

Coating Group	Zinc Coating, oz. per sq.ft. of surface[a]	Wire Lot	Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
			0.99 yr.	1.99 yr.	0.91 yr.	2.12 yr.	0.89 yr.	1.86 yr.	1.01 yr.	1.90 yr.	0.83 yr.	1.94 yr.	0.83 yr.	1.83 yr.	0.83 yr.	1.94 yr.
0.20 to 0.30, Avg. 0.28	0.27	No. 512	G	G	G	G	MG	G	MG	G	G	G	MG	MG	MG	MG
	0.30	No. 410	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
	0.28	No. 411	G	G	G	G	MG	G	MG	G	MG	G	M	M	MG	MG
	0.29	No. 510	G	G	G	G	MG	G	MG	G	MG	G	M	M	MG	MG
	0.29	No. 412	G	G	G	G	MG	G	MG	G	MG	G	M	M	MG	MG
	0.24	No. 511	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
0.25 to 0.35, Avg. 0.30	0.25	No. 315	G	G	G	G	MG	MG	MG	G	G	G	MG	MG	MG	MG
	0.28	No. 215	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
	0.27	No. 117	G	G	G	G	G	G	MG	G	MG	G	MG	MG	MG	MG
	0.38	No. 317	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
	0.36	No. 217	G	G	G	G	G	G	MG	G	MG	G	MG	M	MG	MG
	0.32	No. 316	G	G	G	G	MG	G	MG	G	MG	G	M	MG	MG	MG
	0.30	No. 216	G	G	G	G	G	G	MG	G	MG	G	M	MG	MG	MG
	0.25	No. 115	G	G	G	G	G	G	MG	G	MG	G	M	M	MG	MG
0.35 to 0.45, Avg. 0.38	0.36	No. 520	G	G	G	G	MG	G	MG	G	MG	G	MG	M	MG	MG
	0.35	No. 422	G	G	G	G	MG	G	MG	G	G	G	MG	M	MG	MG
	0.31	No. 423	G	G	G	G	MG	G	MG	G	MG	G	MG	M	MG	MG
	0.44	No. 522	G	G	G	G	MG	G	MG	G	G	G	M	MG	MG	MG
	0.37	No. 282	G	G	G	G	G	G	MG	G	MG	MG	MG	MG	M	G
	0.38	No. 521	G	G	G	G	MG	G	MG	G	G	G	MG	MG	MG	MG
	0.47	No. 421	G	G	G	G	MG	G	MG	G	G	G	MG	MG	MG	MG
0.45 to 0.55, Avg. 0.47	0.44	No. 325	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
	0.50	No. 228	G	G	G	G	G	G	MG	G	MG	G	MG	MG	MG	MG
	0.54	No. 329	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
	0.52	No. 227	G	G	G	G	G	G	MG	G	MG	G	MG	MG	MG	MG
	0.41	No. 125	G	G	G	G	G	G	MG	G	MG	G	MG	MG	MG	MG
	0.54	No. 127	G	G	G	G	G	G	MG	G	MG	G	MG	MG	MG	MG
	0.38	No. 326	G	G	G	G	MG	G	M	G	MG	G	MG	MG	MG	MG
	0.45	No. 226	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	G
	0.47	No. 327	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
	0.45	No. 225	G	G	G	G	MG	G	MG	G	MG	G	M	MG	MG	MG
0.50 to 0.60, Avg. 0.56	0.61	No. 530	M	MG	M	MG	M	MG	M	M	M	M	M	M	M	M
	0.57	No. 432	M	MG	M	MG	M	MG	M	M	M	M	M	MG	M	M
	0.60	No. 531	M	MG	M	MG	M	MG	M	MG	M	M	M	M	M	M
	0.48	No. 431	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
	0.54	No. 430	G	G	G	G	MG	G	MG	MG	G	G	MG	MG	MG	MG

0.60 to 0.70, Avg. 0.65	0.69	No. 338	M	MG	M	MG	M	MG	M	M	M	M	M	M	M	M
	0.68	No. 236	M	MG	M	MG	M	MG	M	M	M	M	M	M	M	M
	0.61	No. 335	MG	MG	M	MG	M	MG	M	MG	M	MG	MG	MG	M	M
	0.63	No. 237	MG	MG	M	MG	M	MG	M	M	M	M	MG	M	M	M
	0.74	No. 135	MG	MG	M	MG	MG	MG	M	MG	M	MG	G	MG	M	M
	0.57	No. 337	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	MG
	0.67	No. 235	G	G	G	G	G	G	MG	G	MG	G	MG	MG	MG	G
	0.65	No. 239	G	G	M	G	G	G	MG	MG	MG	G	MG	MG	MG	MG
	0.67	No. 138	G	G	G	G	G	G	MG	G	MG	G	MG	MG	MG	MG
	0.64	No. 139	G	G	G	G	G	G	MG	G	MG	G	MG	MG	MG	MG
	0.66	No. 336	G	G	G	G	MG	MG	MG	MG	MG	G	MG	MG	MG	MG
	0.60	No. 238	G	G	M	G	G	G	MG	MG	MG	G	MG	MG	MG	G
0.70 to 0.85, Avg. 0.75	0.70	No. 540	MG	MG	MG	MG	M	MG	M	M	M	M	M	MG	M	MG
	0.72	No. 442	M	MG	MG	MG	M	MG	M	M	M	M	M	M	M	MG
	0.79	No. 543	MG	MG	MG	MG	M	MG	M	M	M	MG	MG	MG	M	MG
	0.78	No. 441	MG	MG	MG	MG	MG	MG	M	MG	M	M	MG	M	M	M
	0.70	No. 542	MG	MG	MG	MG	M	MG	M	M	M	M	M	MG	M	MG
	0.74	No. 443	MG	MG	MG	MG	M	MG	M	M	M	M	MG	M	M	MG
	0.74	No. 495	Cr	Cr	Cr	Cr	Cr	Cr	Cr	Cr	....	....	Cr	Cr	Cr	MG
	0.76	No. 541	G	G	G	G	G	G	MG	MG	G	G	MG	MG	MG	MG
	0.76	No. 440	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	MG
	0.87	No. 444	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	MG
0.80 to 1.00, Avg. 0.88	1.05	No. 348	M	MG	M	MG	M	MG	M	M	M	M	M	M	M	M
	0.81	No. 248	MG	MG	M	MG	M	MG	M	M	M	M	M	M	M	M
	0.88	No. 347	M	MG	MG	MG	M	MG	M	MG	MG	M	G	G	M	M
	0.95	No. 246	MG	MG	MG	MG	M	MG	M	M	M	MG	G	MG	M	M
	0.88	No. 346	M	MG	MG	MG	M	MG	M	MG	MG	M	MG	M	M	M
	0.81	No. 245	MG	MG	MG	MG	M	MG	M	M	M	MG	MG	M	M	MG
	0.81	No. 296	Cr	Cr	Cr	Cr	Cr	Cr	Cr	Cr	....	....	Cr	Cr	Cr	....
	0.90	No. 148	MG	MG	M	MG	MG	MG	M	M	M	MG	MG	MG	M	M
	0.85	No. 149	MG	MG	MG	MG	MG	MG	M	M	M	MG	G	MG	M	M
	0.84	No. 345	G	G	G	G	G	G	MG	G	MG	G	MG	MG	MG	G
	0.96	No. 247	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	G
Avg. 1.28	1.35	No. 800	M	MG	M	MG	MG	MG	M	M	....	....	G	MG	....	....
	1.20	No. 801	M	MG	M	MG	MG	MG	M	M	....	....	G	MG	....	....
1.60 to 1.80, Avg. 1.76	2.08	No. 552	M	MG	MG	MG	M	MG	M	M	M	M	M	M	M	MG
	1.83	No. 451	M	MG	MG	MG	M	MG	M	M	M	M	M	M	M	MG
	1.75	No. 350	M	MG	M	MG	M	MG	M	M	M	M	M	M	M	MG
	1.69	No. 252	M	MG	MG	MG	M	M	M	M	M	M	G	G	M	M
	1.65	No. 351	MG	MG	M	MG	M	MG	M	M	M	M	M	M	M	M
	1.76	No. 250	M	MG	M	MG	MG	MG	M	M	M	M	G	M	M	M
	1.69	No. 551	MG	MG	M	MG	M	MG	M	M	MG	MG	G	G	M	MG
	1.50	No. 450	M	MG	MG	MG	MG	MG	M	M	MG	MG	G	G	M	MG
	1.75	No. 352	M	MG	M	MG	MG	MG	M	M	MG	MG	G	G	M	M
	1.86	No. 251	M	MG	MG	MG	M	MG	M	M	M	M	G	G	M	M
	1.86	No. 151	M	M	M	MG	MG	MG	M	M	M	MG	M	M	M	M
Heavy Avg. 2.89	2.80	No. 397	M	MG	MG	MG	M	M	M	M	M	M	MG	MG	M	M
	2.72	No. 298	M	MG	MG	MG	M	M	M	M	M	M	M	MG	M	M
	3.00	No. 299	M	M	MG	MG	MG	MG	M	M	....	....	G	G	....	....

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[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

TABLE I.—*Continued.*

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic, G = gray, Y = yellowed, R = rust of base metal, PHR, PHY = rust or yellowed in pinholes. B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance. D = dark (dirt or soot) to the exclusion of a better observation. MG = intermediate between M and G. GY predominately gray but showing indication of Y. Figures (as 5, 20, 50, 100) are percentages.

	Gage	Wire Lot	Pittsburgh (Brunot Island), Pa.				Sandy Hook, N. J.			Bridgeport, Conn.			State College, Pa.		
			0.68 yr.	0.97 yr.	1.48 yr.	1.94 yr.	0.93 yr.	1.44 yr.	1.90 yr.	0.66 yr.	1.45 yr.	1.90 yr.	0.84 yr.	1.30 yr.	1.76 yr.
Copper-covered wire	11	No. 021, 7.42-oz. coating	G	G	G	G	Br	G	Gr	Br	Br	G	Br	Br	Gr
	9	No. 022, 9.24-oz. coating	G	G	G	G	Br	G	Gr	Br	Br	G	Br	Br	Gr
Lead-coated wires	6	No. 040, 1.40-oz. coating	G	5PHR	6PHR	12PHR	10PHR	37PHR	32PHR	G	10PHR	6PHR	1PHY	20PHR	30PHR
	9	No. 041, 1.48-oz. coating	G	5PHR	8PHR	13PHR	10PHR	25PHR	41PHR	G	8PHR	7PHR	8PHY	20PHR	40PHR
	11	No. 042, 1.68-oz. coating	G	5PHR	8PHR	16PHR	10PHR	30PHR	30PHR	G	10PHR	8PHR	1PHY	10PHR	15PHR
	14½	No. 043, 1.90-oz. coating	G	5PHR	10PHR	20PHR	10PHR	57PHR	55PHR	G	3PHR	6PHR	1PHY	14PHR	20PHR
Corrosion-Resistant Uncoated Wires:															
12-14% Cr., cold drawn	12	No. 001	Br	G	B	B	Y	Y	Y	G	G	G	G	MG	M
	9	No. 004	Br	G	B	B	Y	Y	Y	MG	G	G	G	MG	M
	17	No. 005	Br	G	B	B	Y	Y	Y	MG	G	G	G	M	M
12-14% Cr., air quenched	13	No. 002	B	MG	MG	G	Br	GY	GY	MG	MG	MG	MG	MG	M
	10	No. 006	G	MG	MG	G	Br	GY	GY	MG	MG	MG	G	MG	M
	18	No. 007	B	MG	MG	G	Br	GY	Y	MG	MG	MG	G	MG	M
18% Cr., 8% Ni.	15	No. 003	M	M	M	M	M	M	M	M	M	M	M	M	M
	12	No. 008	M	M	M	M	M	M	M	M	M	M	M	M	M
	20	No. 009	M	M	M	M	M	M	M	M	M	M	M	M	M
	14	No. 015	M	M	M	M	M	M	M	M	M	M	M	M	M

	Gage	Wire Lot	Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
			0.99 yr.	1.99 yr.	0.91 yr.	2.12 yr.	0.89 yr.	1.86 yr.	1.01 yr.	1.90 yr.	0.83 yr.	1.94 yr.	0.83 yr.	1.83 yr.	0.83 yr.	1.94 yr.
Copper-covered wire	11	No. 021, 7.42-oz. coating	Br	Gn	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br
	9	No. 022, 9.24-oz. coating	Br	Gn	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br
Lead-coated wires	6	No. 040, 1.40-oz. coating	G	25PHR	10PHY	18PHY	20PHY	20PHY	4PHY	1R	8PHR	7PHR	G	1PHR	2PHY	5PHR
	9	No. 041, 1.48-oz. coating	G	21PHR	10PHY	16PHY	15PHY	20PHY	6PHY	3R	9PHR	11PHR	2PHR	1PHR	5PHY	16PHR
	11	No. 042, 1.68-oz. coating	G	25PHR	1PHY	13PHY	10PHY	5PHY	2PHY	2R	6PHR	4PHR	2PHR	G	4PHY	12PHR
	14½	No. 043, 1.90-oz. coating	G	10PHR	1PHY	13PHY	G	G	3PHY	2R	4PHR	4PHR	1PHR	G	1PHY	4PHR
Corrosion-Resistant Uncoated Wires:																
12-14% Cr., cold drawn	12	No. 001	M	MG	2SY*	MG	G	G	M	MG	75SR*	81SR*	15SR*	29SR*	18SR*	55SR*
	9	No. 004	M	M	7SY*	10SY*	MG	MG	M	MG	53SR*	66SR*	12SR*	14SR*	22SR*	54SR*
	17	No. 005	M	M	1SY*	10SY*	MG	MG	M	MG	60SR*	86SR*	26SR*	24SR*	33SR*	43SR*
12-14% Cr., air quenched	13	No. 002	M	MG	MG	MG	MG	MG	M	M	28SR*	11SR*	5SR*	4SR*	8SR*	17SR*
	10	No. 006	M	MG	MG	MG	MG	MG	M	MG	25SR*	3SR*	5SR*	1SR*	6SR*	4SR*
	18	No. 007	M	M	M	MG	MG	MG	M	MG	20SR*	40SR*	10SR*	4SR*	11SR*	8SR*
18% Cr., 8% Ni.	15	No. 003	M	M	M	M	M	M	M	M	M	M	10SY*	3SY*	M	M
	12	No. 008	M	M	M	M	M	M	M	M	M	M	3SY*	3SY*	M	M
	20	No. 009	M	M	M	M	M	MG	M	M	M	M	7SY*	6SY*	M	M
	14	No. 015	M	M	M	M	M	MG	M	M	..	..	11SY*	12SY*	..	..

* SY* or SR* indicate respectively: superficial Y and superficial R, the asterisk denoting a speckled appearance.

* SY* or SR* indicate respectively: superficial Y and superficial R, the asterisk denoting a speckled appearance.

[illegible] REPORT OF INSPECTIONS OF BARBED WIRE SPECIMENS

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic, G = gray, Y = yellowed, or rust stained, but not showing actual rough rust of base metal. R = rust of base metal. PHR, PHY = rust or yellowed in pinholes. B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance, D = dark (dirt or soot) to the exclusion of a better observation. MG = intermediate between M and G. GY predominately gray but showing indication of Y.

Coating Group	Zinc Coating, oz. per sq.ft. of surface[a]	Wire[b]	State College, Pa.		Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
			0.42 yr.	0.88 yr.	0.99 yr.	1.99 yr.	0.91 yr.	2.12 yr.	0.89 yr.	1.86 yr.	1.01 yr.	1.90 yr.	0.83 yr.	1.94 yr.	0.83 yr.	1.83 yr.	0.83 yr.	1.94 yr.
0.20 to 0.30	0.30	No. C410	G	G	G	G	G	G	MG	G	MG	MG	G	G	MG	MG	MG	M
	0.24	No. C411	G	G	G	G	G	G	MG	G	MG	G	G	G	MG	MG	MG	M
	0.29	No. C412	G	G	G	G	G	G	MG	G	G	G	G	G	M	M	MG	MG
0.35 to 0.45	0.37	No. C421	G	G	G	G	G	G	MG	G	MG	G	G	G	M	MG	MG	MG
	0.47	No. C422	G	G	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	M
	0.31	No. C420	G	G	G	G	G	G	....	G	MG	G	G	G	MG	MG	MG	MG
0.50 to 0.60	0.48	No. C430	G	G	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	MG
	0.54	No. C431	G	G	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	MG
	0.57	No. C432	M	MG	MG	MG	MG	MG	M	MG	M	M	M	MG	MG	MG	M	M
0.70 to 0.85	0.72	No. C441	MG	MG	MG	MG	MG	MG	M	MG	M	M	MG	MG	MG	MG	M	M
	0.78	No. C442	MG	MG	MG	MG	MG	MG	M	MG	M	M	M	MG	MG	MG	MG	M
	0.74	No. C443	MG	MG	MG	MG	MG	MG	M	MG	M	M	MG	MG	M	MG	MG	M
0.80 to 1.00	0.97	No. C445	MG	MG	MG	MG	MG	MG	M	MG	M	MG	MG	MG	M	M	MG	M
	0.92	No. C446	MG	MG	MG	MG	MG	MG	M	MG	M	MG	MG	MG	MG	M	MG	M
1.60 to 1.80	1.64	No. C450	MG	MG	M	MG	M	MG	M	MG	M	M	MG	MG	MG	MG	MG	M
	1.50	No. C452	MG	MG	M	MG	MG	MG	M	MG	M	M	MG	MG	MG	MG	MG	M
	1.83	No. C451	MG	MG	M	MG	MG	G	M	MG	M	M	MG	MG	MG	MG	MG	M
Heavy Coating	1.99	No. C494	MG	MG	M	MG	MG	MG	M	MG	M	M	MG	MG	MG	MG	M	M
	1.99	No. C494	MG	MG	M	MG	MG	MG	M	MG	M	M	MG	MG	MG	MG	M	M
	2.00	No. C447	MG	MG	M	MG	MG	MG	M	MG	M	M	MG	MG	M	M	M	M
Copper covered....		No. C025	Br	1R	Br	30PHR	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br
(3.97 oz. per sq. ft.)		No. C025	Br	2R	....	....	....	....	....	....	Gr	Gr	....	....	....	....	....	....
Lead coated.......		No. C045	....	....	15PHY	100PHR	5PHY	20PHY	10PHY	15PHY	2PHY	2PHR	3PHR	5PHR	1PHY	1PHR	5PHY	10PHR
(1.83 oz. per sq. ft.)		No. C045	....	....	15PHY	....	5PHY	10PHY	....	....	....	....	3PHY	5PHR	1PHY	1PHR	5PHY	10PHR

[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

[b] These barbed wire numbers do not always correspond to the unfabricated wire numbers as seen below:

Barbed Wire	Unfabricated Wire Lot	Barbed Wire	Unfabricated Wire Lot
No. C410	No. 410	No. C441	No. 442
No. C411	....	No. C442	No. 441
No. C412	No. 412	No. C443	No. 443
No. C421	....	No. C445	....
No. C422	No. 421	No. C446	....
No. C420	No. 423	No. C447	....
No. C430	No. 431	No. C450	....
No. C431	No. 430	No. C452	No. 450
No. C432	No. 432	No. C451	No. 451
		No. C494	....

TABLE III.—REPORT OF INSPECTIONS OF FARM FIELD FENCE SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic, G = gray, Y = yellowed, or rust stained, but not showing actual rough rust of base metal. R = rust of base metal. PHR, PHY = rust or yellowed in pinholes. B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance, D = dark (dirt or soot) to the exclusion of a better observation. MG = intermediate between M and G. GY predominately gray but showing indication of Y.

Coating Group	Zinc Coating, oz. per sq.ft. of surface[a]	Fence	State College, Pa.		Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.		Ithaca, N.Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
			0.42 yr.	0.88 yr.	0.99 yr.	1.99 yr.	0.91 yr.	2.12 yr.	0.89 yr.	1.86 yr.	1.01 yr.	1.90 yr.	0.83 yr.	1.94 yr.	0.83 yr.	1.83 yr.	0.83 yr.	1.94 yr.
0.20 to 0.30, Avg. 0.28	0.27	No. 512....	G	G	G	G	G	G	MG	G	MG	G	G	G	MG	MG	MG	MG
	0.30	No. 410....	G	G	G	G	G	G	MG	G	MG	MG	MG	G	MG	MG	MG	M
	0.28	No. 411....	G	G	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
	0.29	No. 510....	G	G	G	G	G	G	MG	G	MG	G	MG	G	M	MG	MG	MG
	0.29	No. 412....	G	G	G	G	G	G	MG	G	MG	G	MG	G	M	M	MG	MG
	0.24	No. 511....	G	G	G	G	G	G	MG	G	G	G	MG	G	MG	MG	MG	MG
0.25 to 0.35, Avg. 0.30	0.25	No. 315....	G	G	G	G	G	G	MG	MG	M	MG	MG	MG	MG	MG	MG	MG
	0.28	No. 215....	G	G	G	G	G	G	MG	G	GY	GY	G	MG	MG	MG	MG	MG
	0.38	No. 317....	G	G	G	G	G	G	MG	G	MG	G	G	G	M	M	MG	MG
	0.32	No. 316....	G	G	G	G	G	G	MG	G	MG	G	G	G	M	M	MG	MG
	0.30	No. 216....	G	G	G	G	G	G	G	G	MG	G	G	G	M	M	MG	MG
0.35 to 0.45, Avg. 0.38	0.36	No. 520....	G	G	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	MG
	0.35	No. 422....	G	G	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	MG
	0.31	No. 423....	G	G	G	G	G	G	G	G	MG	G	G	MG	MG	MG	MG	MG
	0.44	No. 522....	G	G	G	G	G	G	MG	G	MG	G	G	G	MG	MG	MG	MG
	0.38	No. 521....	G	G	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	MG
	0.47	No. 421....	G	G	G	G	G	G	MG	G	MG	G	G	G	M	MG	MG	MG
0.45 to 0.55, Avg. 0.46	0.44	No. 325....	G	G	G	G	G	G	MG	G	MG	G	G	G	MG	MG	MG	MG
	0.50	No. 228....	G	G	G	G	G	G	G	G	MG	G	G	G	MG	MG	G	MG
	0.51	No. 227....	G	G	G	G	G	G	G	G	MG	G	G	G	MG	M	G	MG
	0.38	No. 326....	G	G	G	G	G	G	MG	G	MG	G	G	MG	MG	MG	MG	MG
	0.47	No. 327....	G	G	G	G	G	G	MG	G	MG	G	G	G	MG	M	MG	MG
	0.45	No. 225....	G	G	G	G	G	G	MG	G	MG	G	G	G	M	M	G	MG
0.50 to 0.60, Avg. 0.54	0.61	No. 530....	MG	MG	MG	MG	MG	MG	M	MG	M	M	M	M	M	MG	M	M
	0.57	No. 432....	MG	MG	MG	MG	MG	MG	M	MG	M	M	M	MG	MG	MG	M	M
	0.60	No. 531....	G	MG	MG	G	MG	MG	M	MG	M	M	MG	MG	MG	MG	M	M
	0.48	No. 431....	G	G	G	G	G	G	MG	G	MG	G	G	G	MG	MG	MG	MG
	0.54	No. 430....	G	G	G	G	G	G	G	G	MG	G	G	G	MG	MG	MG	MG
	0.49	No. 532....	G	MG	G	G	G	G	MG	G	MG	G	MG	G	MG	MG	MG	MG
	0.49	No .433....	G	G	G	G	G	G	MG	G	MG	G	G	G	MG	MG	MG	MG

0.60 to 0.70, Avg. 0.64	0.69	No. 338....	MG	MG	MG	MG	MG	MG	M	MG	M	MG	M	M	MG	MG	M	M
	0.68	No. 236....	MG	MG	MG	MG	MG	MG	MG		M	MG	M	M	MG	MG	M	M
	0.61	No. 335....	MG	MG	MG	MG	MG	MG	M	MG	M	M	MG	MG	MG	MG	MG	M
	0.63	No. 237....	MG	MG	MG	MG	M	MG	MG		M	MG	G	MG	MG	G	MG	M
	0.57	No. 337....	G	G	G	G	G	G	G	G	MG	G	G	G	M	MG	G	MG
	0.67	No. 235....	G	G	G	G	G	G	G		MG	G	G	G	M	M	G	MG
	0.66	No. 336....	G	G	G	G	G	G	G	G	MG	G	G	G	MG	MG	G	MG
	0.60	No. 238....	G	G	G	G	G	G	G		MG	G	G	G	MG	MG	G	MG
0.70 to 0.85, Avg. 0.74	0.70	No. 540....	MG	MG	M	MG	M	MG	M	MG	M	MG	M	M	MG	MG	M	M
	0.72	No. 442....	M	MG	MG	MG	MG	MG	M	MG	M	M	M	MG	MG	MG	M	M
	0.79	No. 543....	G	MG	MG	MG	MG	MG	M	MG	M	MG	MG	MG	MG	G	MG	M
	0.78	No. 441....	MG	MG	MG	MG	MG	MG	M	MG	M	M	MG	MG	MG	MG	M	M
	0.70	No. 542....	MG	MG	M	MG	MG	MG	M	MG	M	M	MG	MG	MG	MG	MG	M
	0.74	No. 443....	MG	MG	MG	MG	MG	MG	M	MG	M	M	MG	MG	MG	MG	MG	M
	0.76	No. 541....	MG	MG	M	MG	MG	MG	M	MG	M	M	MG	MG	MG	G	MG	M
	0.76	No. 440....	MG	MG	MG	MG	MG	MG	M	MG	M	M	MG	MG	MG	MG	M	M
0.80 to 1.00, Avg. 0.90	1.05	No. 348....	M	MG	MG	MG	MG	MG	M	MG	M	M	M	M	M	M	M	M
	0.81	No. 248....	M	MG	MG	G	MG	MG	M	MG	M	MG	M	M	M	M	M	M
	0.88	No. 347....	MG	MG	MG	MG	MG	MG	M	MG	M	M	MG	MG	G	G	MG	M
	0.95	No. 246....	MG	MG	MG	MG	MG	MG	M	MG	M	MG	MG	MG	MG	G	MG	M
	0.88	No. 346....	MG	MG	MG	MG	MG	MG	M	MG	M	MG	MG	MG	MG	MG	MG	M
	0.81	No. 245....	MG	MG	MG	MG	MG	MG	MG	MG	M	MG	MG	MG	MG	G	MG	M
	0.84	No. 345....	G	G	MG	G	G	G	G	G	MG	G	G	G	MG	MG	G	MG
	0.96	No. 247....	G	G	G	G	G	G	G	G	MG	G	G	G	MG	M	G	G
1.60 to 1.80	1.75	No. 350....	MG	MG	M	MG	MG	MG	M	MG	M	M	M	M	M	M	M	M
	1.69	No. 252....	M	MG	M	MG	MG	MG	M	MG	M	MG	M	MG	M	M	M	M
	1.75	No. 352....	MG	MG	M	MG	MG	MG	MG	MG	M	M	MG	MG	MG	G	MG	M
Avg. 2.76	2.80	No. 397....	MG	MG	M	MG	MG	MG	M	MG	M	M	MG	MG	MG	G	M	M
	2.72	No. 298....	MG	MG	M	MG	MG	MG	MG	MG	M	M	MG	MG	MG	MG	M	M
12-14% Cr, cold drawn........		No. 001....	MG	MG	M	MG	MG	MG	MG	MG	MG	MG	30SR*	30SR* 40SY*	20SR*	10SR*	25SR*	75SR*
12-14% Cr, air quenched.....		No. 002....	MG	M	M	MG	MG	MG	MG	MG	M	M	10SR*	5SR* 25SY*	5SR*	5SR*	5SR*	20SR* 50SY*
18% Cr, 8% Ni...		No. 003....	M	M	M	M	M	M	M	M	M	M	M	M	2SY*	2SY*	M	M
Copper covered (7.42 oz. per sq. ft.)............		No. 020....	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br Gn	Br	Br	Br	Br
Lead coated (1.48 oz. per sq. ft.)..		No. 040....	G	3PHR	15PHY	25PHR	15PHY	20PHY	10PHY	15PHY	8PHY	10PHR	5PHR	15PHR	M	1PHR	....	10PHR

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[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

* SY* or SR* indicate, respectively: superficial Y and superficial R, the asterisk denoting a speckled appearance.

TABLE IV.—REPORT OF INSPECTIONS OF CHAIN LINK FENCE SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = Metallic, G = gray, Y = yellowed, or rust stained, but not showing actual rough rust of base metal. R = rust of base metal. PHR, PHY = rust or yellowed in pinholes. B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance, D = dark (dirt or soot) to the exclusion of a better observation. MG = intermediate between M and G. GY predominately gray but showing indication of Y.

All 200 series wires are 9 gage. Lead-coated wire, 9 gage. Corrosion-resistant steel, 14 gage.

All 100 series wires are 6 gage. Copper-covered wire 0.128d.

Zinc Coating, oz. per sq.ft. of surface, by stripping test	Fence	Pittsburgh, Pa.				Sandy Hook, N. J.			Bridgeport, Conn.			State College, Pa.		Lafayette, Ind.		Ithaca, N. Y.		Santa Cruz, Calif.		Davis, Calif.	
		0.68 yr.	0.97 yr.	1.48 yr.	1.94 yr.	0.93 yr.	1.44 yr.	1.90 yr.	0.66 yr.	1.45 yr.	1.90 yr.	0.42 yr.	0.88 yr.	0.99 yr.	1.99 yr.	1.01 yr.	1.90 yr.	0.83 yr.	1.94 yr.	0.83 yr.	1.94 yr.
0.29	No. E280[a]	G	G	51R	100R	GY	GY	10R	MG	G	GY	G	G	G	G	MG	G	G	G	MG	MG
0.52	No. E281	G	G	5Y	37R	GY	GY	2R	MG	G	5R	G	G	G	G	MG	MG	G	G	MG	MG
0.37	No. E282	G	G	10R	100R	G	G	3R	MG	G	G	G	G	G	G	MG	G	G	G	MG	MG
1.22	No. E185	MG	M	G	G	G	MG	GY	M	MG	G	MG	MG	MG	MG	M	M	G	MG	MG	M
1.13	No. E285	G	MG	G	G	G	MG	GY	M	MG	G	MG	MG	MG	MG	M	M	MG	MG	MG	M
2.92	No. E290	MG	M	MG	MG	G	MG	MG	M	M	MG	M	MG	M	M	M	M	MG	MG	MG	5Y
2.09	No. E291	MG	M	MG	MG	G	MG	MG	M	M	MG	MG	MG	M	M	M	M	MG	MG	MG	M
1.60	No. H280[a]	G	M	G	G	G	MG	MG	M	MG	G	MG	MG	MG	MG	M	M	MG	MG	M	M
1.83	No. H185	G	MG	G	G	G	MG	MG	M	MG	MG	MG	MG	MG	MG	M	M	G	MG	MG	M
1.60	No. H186	G	M	G	G	G	MG	MG	M	MG	MG	M	MG	M	MG	M	M	MG	MG	MG	M
1.61	No. H187	G	M	G	G	G	MG	MG	M	MG	MG	M	MG	MG	MG	M	M	MG	MG	M	M
1.55	No. H188	G	M	G	G	G	MG	MG	M	MG	MG	M	MG	M	MG	M	M	MG	MG	M	M
1.36	No. H285	G	MG	G	G	G	MG	MG	M	MG	MG	M	MG	MG	MG	M	M	MG	MG	M	M
1.97	No. H286	G	MG	G	G	G	MG	MG	M	MG	MG	M	MG	MG	MG	M	M	MG	MG	MG	M
1.46	No. H287	G	MG	G	G	G	MG	MG	M	MG	MG	M	MG	MG	MG	M	M	MG	M	G	M
1.74	No. H288	G	MG	G	G	G	MG	MG	M	MG	MG	M	MG	MG	MG	M	M	MG	MG	MG	M
1.40	No. H289[b]	MG	M	G	MG	G	MG	MG	M	MG	MG	M	MG	MG	MG	M	M	MG	M	M	M
4.21	No. H290	MG	M	MG	G	G	MG	MG	M	M	MG	M	MG	M	M	M	MG	M	M	M	M
	Lead-coated L050 (1.75 oz. per sq. ft.)	G	G	5PHR	10PHR	10PHY	20PHR	50PHR	GY	GY	GY	1PHY	5PHY	G	G	1PHY	1PHR	3PHR	5PHR	G	5PHR
	Copper-covered K030 (8.52 oz. per sq. ft.)	G	G	B	G	Gn	Gn	G	Br	Br	G	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br
	Corrosion-resistant steel J011	M	M	M	MG	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

[a] E numbers—coating applied before weaving. H numbers—coating applied after weaving.
[b] While this sample has an H number, its appearance indicates that it was galvanized before weaving.

TABLE V.—REPORT OF INSPECTIONS OF WIRE STRAND SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic, G = gray, Y = yellowed, or rust stained, but not showing actual rough rust of base metal. R = rust of base metal. PHR, PHY = rust or yellowed in pinholes. B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance, D = dark (dirt or soot) to the exclusion of a better observation. MG = intermediate between M and G. GY predominately gray but showing indication of Y.

Zinc Coating, oz. per sq.ft. of surface	Strand	Pittsburgh, Pa.			Sandy Hook, N. J.			Bridgeport, Conn.			State College, Pa.			Lafayette, Ind.	
		0.97 yr.	1.48 yr.	1.94 yr.	0.93 yr.	1.44 yr.	1.90 yr.	0.66 yr.	1.45 yr.	1.90 yr.	0.84 yr.	1.30 yr.	1.84 yr.	0.99 yr.	1.99 yr.
0.69	No. D345	M	MG	G	G	MG	MG	M	M	MG	MG	M	MG	M	MG
0.88	No. D346	MG	G	G	G	MG	MG	M	M	MG	MG	M	MG	M	MG
0.87	No. D347	MG	G	G	G	MG	MG	M	MG	MG	MG	MG	MG	M	MG
0.93	No. D348	M	MG	....	G	MG	MG	M	M	MG	MG	M	MG	M	MG
1.10	No. D360	M	MG	MG	G	MG	MG	M	M	MG	MG	M	MG	M	MG
1.17	No. D361	MG	MG	MG	G	MG	MG	M	MG	MG	MG	MG	MG	M	MG
1.03	No. D362	MG	MG	MG	G	MG	MG	M	M	MG	MG	M	MG	M	MG
1.51	No. D365	MG	MG	MG	G	MG	MG	M	MG	MG	MG	MG	MG	M	MG
1.39	No. D366	M	MG	MG	G	MG	MG	M	M	MG	MG	M	MG	M	MG
1.32	No. D367	MG	MG	MG	G	MG	MG	M	M	MG	MG	M	MG	M	MG
1.71	No. D371	M	MG	MG	G	MG	MG	M	M	MG	MG	M	MG	M	MG
2.47	No. D375	M	MG	MG	G	MG	MG	M	M	MG	MG	M	MG	M	MG
Lead coating (1.96 oz. per sq. ft.)	No. D045	PHR	B	PHR	20PHR	65PHR	70PHR	10PHY	10PHR	20PHR	10PHR	35PHR	60PHR	20PHY	40PHY

Zinc Coating, oz. per sq.ft. of surface	Strand	Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
		0.91 yr.	2.12 yr.	0.89 yr.	1.86 yr.	1.01 yr.	1.90 yr.	0.83 yr.	1.94 yr.	0.83 yr.	1.83 yr.	0.83 yr.	1.94 yr.
0.69	No. D345	MG	MG	M	MG	M	M	MG	M	M	M	M	M
0.88	No. D346	MG	MG	M	MG	M	M	MG	M	MG	MG	M	M
0.87	No. D347	MG	MG	MG	MG	M	M	MG	M	MG	MG	M	M
0.93	No. D348	MG	MG	MG	MG	M	M	MG	M	MG	MG	M	M
1.10	No. D360	MG	MG	M	MG	M	M	MG	M	MG	MG	M	M
1.17	No. D361	MG	MG	M	MG	M	M	MG	M	MG	MG	M	M
1.03	No. D362	MG	MG	M	MG	M	M	MG	M	MG	MG	M	M
1.51	No. D365	MG	MG	MG	MG	M	M	MG	M	MG	MG	M	M
1.39	No. D366	MG	MG	M	MG	M	M	MG	M	MG	MG	M	M
1.32	No. D367	MG	MG	M	MG	M	M	MG	M	MG	MG	M	M
1.71	No. D371	MG	MG	M	MG	M	M	MG	M	MG	MG	M	M
2.47	No. D375	MG	MG	M	MG	M	M	MG	M	MG	MG	M	M
Lead coating (1.96 oz. per sq. ft.)	No. D045	20PHY	20PHY	GY	20PHY	5PHR	9PHR	10PHR	12PHR	GY	2PHR	1PHY	17PHR

TABLE VI.—BREAKING LOADS AND ELONGATION OF UNFABRICATED WIRE SPECIMENS.
(Tests on Unexposed Samples and Successively Removed Companion Samples)
Uncoated Steel Wires—LowCopper Content

Location	Expo-sure, yr.	Break-ing Load, lb.	Elonga-tion in 10 in., per cent	Expo-sure, yr.	Break-ing Load, lb.	Elonga-tion in 10 in., per cent	Expo-sure, yr.	Break-ing Load, lb.	Elonga-tion in 10 in., per cent	Expo-sure, yr.	Break-ing Load, lb.	Elonga-tion in. 10 in,, per cent	Expo-sure, yr.	Break-ing Load, lb.	Elonga-tion in 10 in., per cent
	Wire Lot No. 501			*Wire Lot No. 400*			*Wire Lot No. 401*			*Wire Lot No. 300*			*Wire Lot No. 302*		
Unexposed, first test*	0	500	7.3	0	470	19.2	0	440	17.2	0	730	19.5	0	1100	7.5
Unexposed, second test*	0	500	....	0	490	....	0	460	....	0	750	....	0	1095	....
Pittsburgh, Pa.	1.48	320	0.5	1.48	360	15.5	1.48	320	13.8	1.48	590	17.0	1.48	820	5.0
	1.94	305	0.8	1.94	370	14.3	1.94	335	12.8	1.94	605	16.2	1.94	820	3.8
Sandy Hook, N. J.	1.44	390	1.0	1.44	390	17.5	1.44	370	11.5	1.44	640	18.1	1.44	890	5.4
	1.90	380	0.3	1.90	410	15.0	1.90	380	13.8	1.90	650	18.2	1.90	920	4.3
Bridgeport, Conn.	1.45	420	2.0	1.45	400	14.0	1.45	380	15.0	1.45	660	18.0	1.45	910	5.0
	1.91	385	0.5	1.91	430	18.5	1.91	400	14.3	1.91	....	....	1.91	....	....
State College, Pa.	1.30	440	1.3	1.30	420	18.3	1.30	400	18.0	1.30	670	19.8	1.30	980	7.0
	1.76	445	1.3	1.76	....	....	1.76	....	....	1.76	....	....	1.76	....	....
Ithaca, N. Y.	2.00	440	0.8	2.00	460	18.2	2.00	430	17.7	2.00	705	18.0	2.00	995	6.3
Lafayette, Ind.	1.99	435	1.0	1.99	440	18.2	1.99	405	16.8	1.99	690	18.0	1.99	965	6.0
Ames, Iowa	2.07	455	1.2	2.07	460	17.7	2.07	445	10.0	2.07	710	18.0	2.07	995	5.8
Manhattan, Kans.	1.86	495	1.8	1.86	485	16.8	1.86	465	16.5	1.86	745	17.8	1.86	1065	5.3
College Station, Tex.	1.86	460	1.8	1.86	480	17.3	1.86	460	15.0	1.86	735	17.5	1.86	1050	5.8
Davis, Calif.	1.94	495	1.2	1.94	480	18.3	1.94	465	16.8	1.94	735	18.7	1.94	1050	7.2
Santa Cruz, Calif.	1.94	475	1.0	1.94	475	18.7	1.94	465	17.8	1.94	720	17.8	1.94	1045	6.3
	Wire Lot No. 200			*Wire Lot No. 202*			*Wire Lot No. 101*			*Wire Lot No. 105*					
Unexposed, first test*	0	1010	14.8	0	1640	6.3	0	2330	6.0	0	2750	5.0			
Unexposed, second test*	0	1080	....	0	1635	....	0	2300	....	0	2770	....			
Pittsburgh, Pa.	1.48	830	14.2	1.48	1330	4.2	1.48	2000	4.8	1.48	2400	4.0			
	1.94	845	12.5	1.94	1345	4.7	1.94	2005	4.5	1.94	2385	3.0			
Sandy Hook, N. J.	1.44	890	14.2	1.44	1500	4.7	1.44	2140	4.5	1.44	2500	5.0			
Bridgeport, Conn.	1.45	920	14.0	1.45	1450	4.2	1.45	2130	3.7	1.45	2530	3.7			
State College, Pa.	1.30	970	15.3	1.30	1600	5.3	1.30	2190	5.0	1.30	2580	4.8			
Ithaca, N. Y.	2.00	965	11.7	2.00	1595	6.3	2.00	2255	4.2	2.00	2635	3.8			
Lafayette, Ind.	1.99	950	14.7	1.99	1505	5.3	1.99	2185	3.8	1.99	2560	2.7			
Ames, Iowa	2.07	965	14.0	2.07	1585	5.7	2.07	2210	4.2	2.07	2645	4.0			
Manhattan, Kans.	1.86	1010	13.2	1.86	1645	5.2	1.86	2295	3.8	1.86	2605	3.3			
College Station, Tex.	1.86	1020	14.7	1.86	1575	4.2	1.86	2295	4.0	1.86	2695	4.2			
Davis, Calif.	1.94	995	13.3	1.94	1635	5.7	1.94	2295	5.0	1.94	2765	5.2			
Santa Cruz, Calif.	1.94	1000	11.8	1.94	1675	4.2	1.94	2345	5.3	1.94	2645	4.2			

Uncoated Steel Wires—Copper Bearing

	Wire Lot No. 506			*Wire Lot No. 507*			*Wire Lot No. 405*			*Wire Lot No. 406*			*Wire Lot No. 305*		
Unexposed, first test*	0	520	7.3	0	590	1.3	0	470	20.0	0	406	17.8	0	1070	8.3
Unexposed, second test*	0	520	....	0	600	....	0	495	....	0	475	....	0	1100	....
Pittsburgh, Pa.	1.48	350	1.0	1.48	410	1.0	1.48	370	14.8	1.48	370	15.5	1.48	870	5.5
	1.94	335	0.7	1.94	380	0.3	1.94	370	12.8	1.94	370	13.8	1.94	920	5.3
Sandy Hook, N. J.	1.44	390	1.3	1.44	460	....	1.44	390	14.5	1.44	380	15.5	1.44	950	6.3
	1.90	390	0.5	1.90	440	0.5	1.90	410	13.8	1.90	400	15.8	1.90	925	6.3
Bridgeport, Conn.	1.45	410	1.0	1.45	490	1.0	1.45	400	16.0	1.45	400	18.0	1.45	990	5.0
	1.91	430	0.3	1.91	490	0.2	1.91	420	16.8	1.91	430	17.8	1.91	....	....
State College, Pa.	1.30	430	....	1.30	500	1.0	1.30	420	19.2	1.30	410	19.5	1.30	990	8.2
	1.76	450	0.5	1.76	510	0.7	1.76	....	....	1.76	....	....	1.76	....	....
Ithaca, N. Y.	2.00	465	0.7	2.00	540	0.2	2.00	455	18.3	2.00	450	20.0	2.00	1010	7.7
Lafayette, Ind.	1.99	460	0.8	1.99	510	0.8	1.99	435	17.8	1.99	435	17.8	1.99	1010	5.8
Ames, Iowa	2.07	460	0.8	2.07	545	0.7	2.07	465	15.0	2.07	450	18.5	2.07	1035	6.8
Manhattan, Kans.	1.86	515	0.8	1.86	620	1.0	1.86	520	9.8	1.86	475	17.7	1.86	1085	7.2
College Station, Tex.	1.86	505	1.0	1.86	575	0.8	1.86	485	17.8	1.86	465	18.8	1.86	1060	6.8
Davis, Calif.	1.94	505	1.0	1.94	600	0.7	1.94	475	17.0	1.94	465	18.7	1.94	1075	7.5
Santa Cruz, Calif.	1.94	495	1.0	1.94	595	0.8	1.94	470	17.5	1.94	460	17.5	1.94	1065	7.2

	Wire Lot No. 306			*Wire Lot No. 205*			*Wire Lot No. 206*			*Wire Lot No. 102*			*Wire Lot No. 106*		
Unexposed, first test*	0	700	19.8	0	1100	16.5	0	1480	11.2	0	2110	10.8	0	2430	3.3
Unexposed, second test*	0	720	....	0	1100	....	0	1480	....	0	2075	....	0	2365	....
Pittsburgh, Pa.	1.48	590	17.8	1.48	930	14.3	1.48	1250	9.0	1.48	1810	9.3	1.48	2310	2.3
	1.94	605	17.0	1.94	985	12.7	1.94	1235	8.7	1.94	1805	9.8	1.94	2205	1.7
Sandy Hook, N. J.	1.44	610	19.0	1.44	970	13.8	1.44	1280	9.3	1.44	1850	11.3	1.44	2270	2.5
	1.90	625	17.2	1.90	....	....	1.90	....	....	1.90	....	....	1.90	....	....
Bridgeport, Conn.	1.45	660	18.0	1.45	1020	14.7	1.45	1330	9.1	1.45	1860	10.8	1.45	2300	2.3
State College, Pa.	1.30	650	18.0	1.30	1010	15.3	1.30	1350	10.5	1.30	1940	11.5	1.30	2360	2.8
Ithaca, N. Y.	2.00	690	19.5	2.00	1075	12.5	2.00	1405	10.8	2.00	1935	10.3	2.00	2380	2.2
Lafayette, Ind.	1.99	670	17.5	1.99	1025	14.0	1.99	1375	9.2	1.99	1870	9.2	1.99	2345	2.0
Ames, Iowa	2.07	680	18.0	2.07	1090	13.7	2.07	1390	8.7	2.07	2000	8.7	2.07	2445	1.3
Manhattan, Kans.	1.86	720	18.8	1.86	1110	12.5	1.86	1465	9.8	1.86	2035	10.0	1.86	2445	1.5
College Station, Tex.	1.86	705	17.5	1.86	1105	12.0	1.86	1445	9.3	1.86	1975	11.0	1.86	2445	2.8
Davis, Calif.	1.94	710	18.7	1.94	1090	12.5	1.94	1460	9.3	1.94	1990	11.5	1.94	2415	3.2
Santa Cruz, Calif.	1.94	705	17.7	1.94	1085	13.8	1.94	1420	9.2	1.94	1970	11.3	1.94	2345	4.2

* The first test was made in November, 1937, approximately one year after companion samples were exposed.
The second test was made in April, 1939.

TABLE VI.—(*Continued.*)
Zinc-Coated and Lead-Coated Steel Wires

Location	Exposure, yr.	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent
Zinc Coated:		*Wire Lot No. 510*			*Wire Lot No. 511*			*Wire Lot No. 512*			*Wire Lot No. 410*			*Wire Lot No. 411*			*Wire Lot No. 412*		
Unexposed, first test*	0	....	500	1.8	....	280	20.5	....	320	19.1	....	570	18.0	....	630	6.0	....	840	7.2
Unexposed, second test*	0	....	500	....	....	290	....	....	330	....	....	575	....	....	600	....	....	820	....
Pittsburgh, Pa.	1.48	1.20	500	1.0	0.60	210	15.0	0.50	240	13.0	0.65	470	14.8	0.85	560	5.5	1.25	790	6.4
	1.94	1.20	455	1.0	0.60	205	11.5	0.50	235	11.0	0.65	465	11.2	0.85	555	6.0	1.25	760	4.2
Sandy Hook, N. J.	1.44	1.75	490	....	1.75	250	19.2	1.55	290	16.5	1.80	550	15.0	1.85	650	7.7	1.85	790	7.4
	1.90	1.75	510	0.8	1.75	290	18.3	1.55	310	15.8	1.80	....	....	1.85	....	....	1.85	....	....
Bridgeport, Conn.	1.45	1.85	510	1.0	1.80	260	19.2	1.65	300	17.7	1.80	550	18.0	1.90	600	4.8	1.85	830	7.5
	1.91	1.85	530	1.0	1.80	290	20.5	1.65	320	15.5	1.80	600	15.5	1.90	685	6.3	1.85	835	6.8
		Wire Lot No. 315			*Wire Lot No. 316*			*Wire Lot No. 317*			*Wire Lot No. 215*			*Wire Lot No. 216*			*Wire Lot No. 217*		
Unexposed, first test*	0	....	890	13.3	....	1010	8.2	....	780	14.5	....	1200	14.7	....	1630	8.5	....	1080	10.8
Unexposed, second test*	0	....	910	....	....	1160	....	....	805	....	....	1220	....	....	....	....	....	1080	....
Pittsburgh, Pa.	1.48	0.45	770	12.0	1.20	1110	7.2	1.45	....	....	0.60	1100	11.7	1.30	1600	7.2	1.05	1060	8.5
	1.94	0.45	820	9.7	1.20	1070	7.3	1.45	750	14.5	0.60	1100	11.0	1.30	1530	6.3	1.05	1080	9.0
Sandy Hook, N. J.	1.44	1.60	910	11.5	1.85	1120	7.5	1.90	....	....	1.80	1190	14.0	1.85	1600	8.0	1.85	1150	9.5
Bridgeport, Conn.	1.45	1.70	900	11.5	>2	1100	7.8	>2	....	....	1.85	1200	12.8	>2	1630	7.7	>2	1140	9.2
		Wire Lot No. 115			*Wire Lot No. 117*														
Unexposed, first test*	0	....	2690	7.8	....	2230	10.7												
Unexposed, second test*	0	....	2740	....	....	2200	....												
Pittsburgh, Pa.	1.48	0.65	2650	5.5	0.75	2090	9.8												
	1.94	0.65	2505	6.5	0.75	2090	10.3												
Sandy Hook, N. J.	1.44	1.75	2650	6.3	1.85	2200	9.8												
Bridgeport, Conn.	1.45	1.75	2680	6.5	>2	2140	12.0												
		Wire Lot No. 520			*Wire Lot No. 521*			*Wire Lot No. 522*			*Wire Lot No. 421*			*Wire Lot No. 422*			*Wire Lot No. 423*		
Unexposed*	0	....	280	18.7	....	270	20.0	....	500	1.5	....	470	19.3	....	500	15.8	....	400	17.2
Pittsburgh, Pa.	1.48	1.20	280	18.0	1.75	280	19.8	1.45	510	1.0	1.60	450	17.2	1.45	460	16.2	1.25	370	18.0
	1.94	1.20	275	17.2	1.75	285	13.7	1.45	475	1.0	1.60	455	13.0	1.45	475	14.7	1.25	370	16.0
Sandy Hook, N. J.	1.44	1.85	270	16.5	1.85	260	17.5	1.85	490	....	1.80	440	15.4	1.80	470	15.3	1.80	370	15.3
Lead Coated:		*Wire Lot No. 040*			*Wire Lot No. 041*			*Wire Lot No. 042*			*Wire Lot No. 043*								
Unexposed, first test*	0	....	1790	9.5	....	1070	12.8	....	670	13.0	....	300	17.1						
Pittsburgh, Pa.	1.48	0.9	1780	9.8	0.9	1060	11.2	0.9	660	11.0	0.9	260	12.8						
Sandy Hook, N. J.	1.44	0.9	1780	8.2	0.9	1040	10.8	0.9	660	12.5	0.9	270	13.0						
Bridgeport, Conn.	1.45	1.4	1770	8.5	1.4	1050	11.5	1.4	660	10.8	1.4	260	13.5						
State College, Pa.	1.30	1.4	1780	10.3	1.4	1050	12.0	1.4	660	12.0	1.4	280	15.0						
Ithaca, N. Y.	2.00	....	....	....	....	....	....	....	....	....	1.5	310	14.7						
Lafayette, Ind.	1.99	....	....	....	....	....	....	....	....	....	1.5	310	14.7						
Ames, Iowa	2.07	....	....	....	....	....	....	....	....	....	>2	310	14.0						
Manhattan, Kans.	1.86	....	....	....	....	....	....	....	....	....	>2	310	15.0						

REMOVALS FROM PITTSBURGH ONLY
Zinc-Coated Steel Wires

Wire Lot	First Rust, yr.	Breaking Load, lb.			Elongation in 10 in., per cent		
		Unexposed*	Exp. 1.48 yr.	Exp. 1.94 yr.	Unexposed*	Exp. 1.48 yr.	Exp. 1.94 yr.
No. 530	1.20	310	280	270	10.0	10.0	8.0
No. 531	1.40	500	460	425	4.0	2.8	0.8
No. 540	1.85	300	....	320	10.2	....	6.7
No. 541	>2	350	....	355	15.0	....	16.3
No. 542	1.65	510	....	510	3.5	....	0.8
No. 543	1.85	300	....	305	14.2	....	6.3
No. 430	>2	780	790	815	6.5	5.3	6.2
No. 431	1.60	880	820	780	6.8	7.2	4.7
No. 432	1.60	510	520	460	9.2	6.8	8.8
No. 325	1.75	730	720	745	18.7	16.0	17.7
No. 326	1.40	700	670	610	15.8	15.2	13.3
No. 327	1.80	1160	1120	1135	7.0	7.5	4.2
No. 329	1.85	720	710	750	14.7	13.3	15.0
No. 225	1.90	1650	1630	1635	6.7	5.8	5.7
No. 226	1.90	1150	1110	1170	18.2	14.8	16.2
No. 227	1.95	1640	1590	1570	7.0	7.0	6.7
No. 228	1.60	1080	1080	1085	14.7	14.5	13.7
No. 237	1.90	1540	....	1585	6.7	....	5.5
No. 238	1.90	1650	....	1685	8.3	....	7.2
No. 239	>2	1120	....	1130	17.7	....	16.2
No. 245	>2	1570	....	1605	7.3	....	5.5
No. 282	1.45	1320	....	1310	13.0	....	10.5
No. 125	1.45	1840	1840	1785	16.8	14.7	15.8
No. 127	1.70	2540	2610	2560	7.5	6.5	5.0

* The first test was made in November, 1937, approximately one year after companion samples were exposed.
The second test was made in April, 1939.

TABLE VII.—LOSS OF WEIGHTS OF ZINC-COATED WIRES.

(Tests on unfabricated wires weighed and measured before exposure.)

Losses of Weight in grams per square foot of specimens exposed 1.30 to 1.94 yr.

Gage of Wire	Group A[a]			Group B[a]			Group C[a]			Averages of Like Gages
	Wire Lot	Rack Exposure		Wire Lot	Rack Exposure		Wire Lot	Rack Exposure		
		West Side	East Side		West Side	East Side		West Side	East Side	
					PITTSBURGH EXPOSURES (1.48 YR.)					
6	No. 148	14.9 14.5	13.9 14.3							14.4
9				No. 247	14.6 15.5	14.3 14.1	No. 248	14.7 14.5	14.5 14.8	14.6
11	No. 346	16.8 16.8	16.4 16.8	No. 345	16.0 15.7	16.0 15.5	No. 348	14.9 15.1	15.2 15.0	15.9
14½	No. 542	18.8 15.5	18.6 22.2	No. 541	16.5 16.7	16.6 16.5	No. 540	18.2 17.8	18.0 18.0	17.8
	Avg.	16.5	17.0	Avg.	15.9	15.4	Avg.	15.9	15.9	
					PITTSBURGH EXPOSURES (1.94 YR.)					
6	No. 148	19.3 19.0	17.6 22.0							19.5
9				No. 247	19.8 19.5	19.6 19.2	No. 248	17.2 17.4	17.5 17.2	18.4
11	No. 346	21.8 21.9	21.1 21.5	No. 345	20.1 20.7	19.8 19.8	No. 348	18.9 18.9	18.7 18.9	20.2
14½	No. 542[b]	59.2 53.9	46.1 52.6	No. 541	20.9 20.5	20.1 20.6	No. 540	20.6 21.7	20.4 20.3	20.6
	Avg.	20.5	20.5	Avg.	20.2	19.8	Avg.	19.1	18.8	

SANDY HOOK EXPOSURES (1.44 YR.)

6	No. 148	4.5 4.6	4.6 4.9							4.6
9				No. 247	5.0 5.4	2.9 6.0	No. 248	4.2 4.3	4.5 4.4	4.6
11	No. 346	4.9 4.5	4.9 5.1	No. 345	5.8 5.5	5.6 5.4	No. 348	4.6 4.4	4.6 4.7	5.0
14½	No. 542	5.5 5.5	5.6 5.7	No. 541	5.5 5.8	6.4 5.4	No. 540	5.3 5.3	5.5 5.4	5.6
	Avg.	4.9	5.1	Avg.	5.5	5.8	Avg.	4.7	4.9	

STATE COLLEGE EXPOSURE (1.30 YR.)

6	No. 148	2.6 2.5	2.6 2.5							2.6
9				No. 247	3.1 3.0	3.1 3.2	No. 248	1.8 1.8	2.0 1.7	2.5
11	No. 346	2.3 2.3	2.2 2.4	No. 345	2.9 3.2	3.0 3.0	No. 348	2.1 2.1	3.2 2.1	2.6
14½	No. 542	2.9 2.8	2.8 2.9	No. 541	2.6 2.8	3.0 2.9	No. 540	2.8 2.5	2.6 2.9	2.5
	Avg.	2.6	2.6	Avg.	2.9	3.0	Avg.	2.2	2.5	

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[a] By reference to the published referee tests results, the wires listed under group A, (or B or C) will be found to be closely alike as regards base metal composition and coating characteristics.

[b] Samples partly rusted, not included in the averages.

NOTE: The loss in weight is expressed in grams per square foot because these units are of a convenient size. The loss in weight may be converted to ounces per square foot by multiplying the tabulated figures by 0.035.

PLATE I
PROCEEDINGS, AM. SOC. TESTING MATS.
VOL. 39
REPORT OF COMMITTEE A-5:
WIRE INSPECTION REPORT

REFERENCE INFORMATION

ON UNFABRICATED WIRE, BARBED WIRE AND FENCE IN THE WIRE INSPECTION REPORT.

The Wire Test Committee responsible for planning and arranging the exposure tests of specimens covered in this report recommends that the following statement be made in all reports relating to the samples of wire and wire products under exposure tests:

"It is emphasized that the weight of coating ranges shown under each weight group have been arbitrarily chosen and purposely held to close limitations by the Committee and do not necessarily individually represent any manufacturers' commercial product. On the other hand, the entire range of coatings covered by all weight groups as a whole are designed to include a sufficient range of coating to furnish the useful corrosion resistance data desired."

SYSTEM OF NUMBERING SPECIMENS

Zinc coated and uncoated steel specimens (all have 3-digit numbers)..................(c)

When the first digit is.......	5	4	3	2	1
the respective gages are:	14.5	12.5	11	9	6

The second and third digits indicate weight of zinc coating as follows:

	oz. per sq.ft.		oz. per sq.ft.
00-04 (LC)*	uncoated	50-59 (CB)	1.6 to 1.8
05-09 (CB)*	uncoated	60-64 (CB)	1.0 to 1.2
10-14 (CB)	0.20 to 0.30	65-69 (CB)	1.3 to 1.5
15-19 (CB)	0.25 to 0.35	70-74 (CB)	1.6 to 1.8
20-24 (CB)	0.35 to 0.45	75-79 (CB)	2.4 to 2.6
25-29 (CB)	0.45 to 0.55	80-84 (CB)	less than 0.50
30-34 (CB)	0.50 to 0.60	85-89 (CB)	1.2 to 1.5
35-39 (CB)	0.60 to 0.70	90-94 (CB)	2.4 to 3.0
40-44 (CB)	0.70 to 0.85	97-99 (CB)	extra heavy
		95-96 (CB)	chromated after coating
45-49 (CB)	0.80 to 1.00 on farm fence and unfabricated wire. 0.85 to 1.00 on barbed wire. 0.80 to 0.95 on wire strand.		

Specimens of Special Materials:
- 000-015: uncoated corrosion-resistant steel.
- 020-030: copper-covered steel.
- 040-050: lead-coated steel.

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* LC = low copper content wire; CB = copper bearing wire.

Reference Characters

(a)......Wire lot numbers identify wire from a coil or coils of wire supposedly alike.

Wire Lots of Zinc-Coated or Bare Mild Steel	Usually Appear in the Test as shown by ✓				
	Unfab. + Wire	Int. of + Fence	T and B + of Fence	T and B of Fence	Barbed Wire
100 series	✓ (S)	....	....	....	....
200 series	✓ (S)	✓ (S)	✓ (S)	✓ (300)	....
300 series	✓ (S)	✓ (S)	....	✓ (500)	....
400 series	✓ (S)	✓ (S)	....	....	✓ (400)
(s)...... 500 series	✓ (S)	✓ (S)	....	....	....

(S) The specimen numbers of the unfabricated wire or fence are the same as the wire lot numbers.

(300), (400), (500): Specimens of fence numbered in the series 300 have top and bottom wires of the 200 series wire lots; fences numbered in the 500 series have top and bottom wires of the 300 series wire lots. Specimens of barbed wire (numbered in the 400 series) have wire lots of the 400 series but not necessarily of the same identical wire lot numbers.

Par. A. The zinc-coated wire lots table below shows:

(1) All the individual numbered wire lots and the various utilizations of each wire lot in the test.

(2) The results of weight of coating tests on samples cut from each source (unfabricated wire, fence interiors, fence top and bottom wires, and barbed wires).

(b)...... (3) The average coating for each wire lot which is the average of all the figures in the third and following columns in each row.

These average coating figures are the ones entered in other tables of this report. For example, wherever unfabricated wire sample No. 317 or farm fence sample No. 317 are listed, their indicated weights of coating are 0.38 oz. per sq.ft., and not 0.46 and 0.34, respectively.

These wire lot and coating reference data provide an indication of the uniformity of coating on any wire lot.

Par. B. The makeup of fences table below shows:

(1) The lot number of the wire used in the top and bottom line wires of each fence. (The lot number of the wire used in the interior line and stay wires of any fence is the same as the fence number.)

(2) The type of fence, that is, the combination of gages used in its fabrication as explained below:

(d)......				
Type of fence...........................	4	3	2	1
Gage of interior line and stay wires....	14.5	12.5	11	9
Gage of top and bottom line wires......	11	10	9	9

+ ......Abbreviations: Unfab., unfabricated wire; Int., interior line and stay wire; T and B, top and bottom line wires.

ZINC-COATED WIRE LOTS: THEIR COATING WEIGHTS AND TEST SPECIMENS IN WHICH THEY ARE USED

(See Par. A and reference characters above for explanations) (Coating weights, oz. per sq.ft.)

Wire Lot (a) (Fence)	(b) Average Coating	Coating Weight Tests on Samples Cut From Unfab. Wire(s)	Fence Int.(s)	Barbed Wire Coating	Barbed Wire No.
No. 510(c)	0.29	0.29	0.29		
No. 511	0.24	0.24	0.23		
No. 512	0.27	0.27	0.27		
No. 520	0.36	0.34	0.38		
No. 521	0.38	0.40	0.36		
No. 522	0.44	0.44	0.44		
No. 530	0.61	0.59	0.62		
No. 531	0.60	0.58	0.61		
No. 532	0.49	....	0.49		
No. 540	0.70	0.72	0.68		
No. 541	0.76	0.80	0.72		
No. 542	0.70	0.69	0.71		
No. 543	0.79	0.83	0.74		
No. 551	1.69	1.69	....		
No. 552	2.08	2.08	....		
No. 410(c)	0.30	0.25	0.38	0.27	(410)
No. 411	0.28	0.28	0.28	....	....
No. 412	0.29	0.30	0.30	0.27	(412)
No. 421	0.47	0.49	0.49	0.44	(422)
No. 422	0.35	0.38	0.31	....	....
No. 423	0.31	0.35	0.31	0.28	(420)
No. 430	0.54	0.56	0.52	0.53	(431)
No. 431	0.48	0.49	0.48	0.46	(430)
No. 432	0.57	0.58	0.60	0.53	(432)
No. 433	0.49	....	0.49	....	....
No. 440	0.76	0.72	0.79	....	....
No. 441	0.78	0.77	0.76	0.82	(442)
No. 442	0.72	0.65	0.86	0.64	(441)
No. 443	0.74	0.74	0.78	0.70	(443)
No. 444	0.87	0.87	....	....	....
No. 450	1.50	1.48	....	1.52	(452)
No. 451	1.83	1.71	....	1.95	(451)
No. 495 Cr	Made from unfab. wire 443.				

	Unfab. Wire
No. 115(c)......	0.25
No. 117.........	0.27
No. 125.........	0.41
No. 127.........	0.54
No. 135.........	0.74
No. 138.........	0.67

	Unfab. Wire
No. 139............	0.64
No. 148............	0.90
No. 149............	0.85
No. 151............	1.86
No. 800(6 ga.).....	1.35
No. 801(9 ga.).....	1.20

Wire Lot (a) (Fence)	(b) Average Coating	Coating Weight Tests on Samples Cut From Unfab. Wire(s)	Fence Int.(s)	T and B of Fence Top	T and B of Fence Bottom	T and B of Fence No.
No. 315(c)	0.25	0.25	0.25	0.25	0.26	(512)
No. 316	0.32	0.32	0.31	0.32	0.33	(510)
No. 317	0.38	0.46	0.34	0.37	0.36	(511)
No. 325	0.44	0.50	0.52	0.37	0.39	(520)
No. 326	0.38	0.40	0.35	....	....	....
No. 327	0.47	0.48	0.44	0.48	0.48	(522)
No. 329	0.54	0.56	....	0.45	0.61	(521)
No. 335	0.61	0.61	0.63	0.59	0.60	(531)
No. 336	0.66	0.73	0.60	....	....	....
No. 337	0.57	0.66	0.59	0.50	0.52	(532)
No. 338	0.69	0.67	0.76	0.67	0.65	(530)
No. 345	0.84	0.83	0.97	0.76	0.79	(541)
No. 346	0.88	0.84	0.84	0.96	0.88	(542)
No. 347	0.88	0.96	1.00	0.78	0.79	(543)
No. 348	1.05	1.04	1.07	1.05	1.06	(540)
No. 350	1.75	1.73	1.76	....	....	....
No. 351	1.65	1.65	....	....	....	....
No. 352	1.75	1.82	1.68	....	....	....
No. 397	2.80	2.80	2.79	....	....	....

Wire Lot (a) (Fence)	(b) Average Coating	Unfab. Wire(s)	Fence(s) T-B Top	Fence(s) T-B Bottom	T and B of Fence Top	T and B of Fence Bottom	T and B of Fence No.
No. 215(c)	0.28	0.28	0.25	0.25	0.33	0.29	(315)
No. 216	0.28	0.31	0.30	0.31	0.27	0.29	(316)
No. 217	0.36	0.29	....	....	0.40	0.39	(317)
No. 225	0.45	0.45	0.49	0.44	0.43	0.47	(327)
No. 226	0.45	0.46	....	....	0.45	0.45	(326)
No. 227	0.51	0.59	0.48	0.49	....	....	
No. 228	0.50	0.49	0.48	0.48	0.50	0.53	(325)
No. 235	0.67	0.82	0.60	0.62	0.68	0.64	(337)
No. 236	0.68	0.66	0.68	0.73	0.69	0.65	(338)
No. 237	0.63	0.72	0.67	0.55	0.58	0.61	(335)
No. 238	0.60	0.60	0.59	0.61	0.59	0.61	(336)
No. 239	0.65	0.65	....	....	....	....	....
No. 245	0.81	0.80	0.83	0.78	0.81	0.81	(346)
No. 246	0.95	0.97	0.94	0.98	0.89	0.95	(347)
No. 247	0.96	0.94	0.95	1.00	1.01	0.91	(345)
No. 248	0.81	0.66	0.92	0.68	0.91	0.89	(348)
No. 250	1.76	1.76	....	....	....	....	....
No. 251	1.86	1.68	....	....	1.99	1.91	(352)
No. 252	1.69	1.67	1.85	1.57	....	....	(350)
No. 282	0.37	0.37	....	....	....	....	....
No. 296 Cr	Made from unfab. wire 245.						
No. 298	2.72	2.78	2.71	2.74	2.71	2.67	(397)
No. 299	3.00	3.00	....	....	....	....	....

MAKEUP OF FENCES

(See Par. B and reference characters above)

ZINC-COATED FENCES

Int. Lot (Fence)	Type (d)	T-B Lot	Int. Lot (Fence)	Type (d)	T-B Lot
No. 510	4	No. 316	No. 410	3	....
No. 511	4	No. 317	No. 411	3	....
No. 512	4	No. 315	No. 412	3	....
No. 520	4	No. 325	No. 421	3	....
No. 521	4	No. 329	No. 422	3	....
No. 522	4	No. 327	No. 423	3	....
No. 530	4	No. 338	No. 430	3	....
No. 531	4	No. 335	No. 431	3	....
No. 532	4	No. 337	No. 432	3	....
No 540	4	No. 348	No. 433	3	....
No. 541	4	No. 345	No. 440	3	....
No. 542	4	No. 346	No. 441	3	....
No. 543	4	No. 347	No. 442	3	....
			No. 443	3	....
No. 315	2	No. 215			
No. 316	2	No. 216	No. 215	1	No. 215
No. 317	2	No. 217	No. 216	1	No. 216
No. 325	2	No. 228	No. 225	1	No. 225
No. 326	2	No. 226	No. 227	1	No. 227
No. 327	2	No. 225	No. 228	1	No. 228
No. 335	2	No. 237	No. 235	1	No. 235
No. 336	2	No. 238	No. 236	1	No. 236
No. 337	2	No. 235	No. 237	1	No. 237
No. 338	2	No. 236	No. 238	1	No. 238
No. 345	2	No. 247	No. 245	1	No. 245
No. 346	2	No. 245	No. 246	1	No. 246
No. 347	2	No. 246	No. 247	1	No. 247
No. 348	2	No. 248	No. 248	1	No. 248
No. 350	2	No. 252	No. 252	1	No. 252
No. 352	2	No. 251	No. 298	1	No. 298
No. 397	2	No. 298			

BARE-STEEL FENCES

Int. Lot (Fence)	Type (d)	T-B Lot	Int. Lot (Fence)	Type (d)	T-B Lot
No. 505	4	No. 306	No. 305	2	No. 206
No. 506	4	No. 305	No. 306	2	No. 207
No. 405	3	....	No. 205	1	No. 205
No. 406	3	....	No. 206	1	No. 206

Coppered-covered steel fence No. 020	Int. No. 021	2	No. 022
Lead-coated steel fence No. 040	Int. No. 041	1	No. 041

UNCOATED CORROSION-RESISTANT STEEL FENCES

No. 001 (T - B Lot No. 001) Gages: Int. 12 ; T - B 12
No. 002 (T - B Lot No. 002) Gages: Int. 12.5; T - B 12.5
No. 003 (T - B Lot No. —) Gages: Int. 15 ; T - B 13

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REPORT OF COMMITTEE A-6

ON

MAGNETIC PROPERTIES

Committee A-6 on Magnetic Properties has held two meetings since its previous report: one in Atlantic City, N. J., on June 29, 1938, and one in Washington, D. C., on April 3, 1939.

Due to the fact that the several subcommittees adequately handle the preparation of specifications, it was decided to eliminate Subcommittee II on Specifications (P. H. Dike, chairman). The personnel of this committee has been assigned to other subcommittees.

During the year the following additions have been made to the personnel of Committee A-6: Elmer Bye of the Simonds Saw and Steel Co. (succeeding H. A. Pavitt); R. C. Taylor of the Western Union Telegraph Co.; W. J. Morris of the Republic Steel Corp. (succeeding W. C. Carroll). A. W. Smith of the University of Michigan has resigned.

I. NEW TENTATIVE STANDARD

In the design and construction of the cores of electrical apparatus, the amount of space occupied by the lamination is an important factor. This is affected by the condition of the surface of the sheets as the result of rolling, heat-treating, and pickling conditions. It is also a function of the coatings which may be used to insulate the laminations from each other. A variety of methods have been used in the past for determining lamination factor and it seems desirable to make available some standard test method. After several months of study by Subcommittee IV on Alternating Current Test Methods, a proposed Method of Test for Measuring Lamination Factor of Steel[1] has been developed which the committee recommends be accepted for publication as tentative. This is simply a test method and no limits are to be specified. It should be useful not only in connection with material as received from the manufacturer, but for tests of the effect of different insulating enamels on core volume. It is intended that the method, when adopted as standard, will be added to the Standard Methods of Test for Magnetic Properties of Iron and Steel (A 34 – 38).[2]

II. REVISIONS OF STANDARDS

The committee recommends for immediate adoption the revision given below in the Standard Methods of Test for Magnetic Properties of Iron and Steel (A 34 – 38),[2] and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that this modification may be referred to letter ballot of the Society:

Section 4 (c).—At the end of this paragraph add the following:

> Should the average density, rather than the assumed density, be required for commercial grades of silicon alloy steels in sheet or plate form, for electrical purposes, the following equations may be used for any silicon content up to about 6 per cent, at approximately 20 C.:
>
> For sheets or plates, free of surface oxides:
> $D = 7.865 - (0.065 \times \text{silicon, per cent})$ . . Eq. (1)
> For sheets with normal thin tight surface oxides:
> $D = 7.80 - (0.0688 \times \text{silicon, per cent})$ . . Eq. (2)
> where D = density in grams per cubic centimeter.

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[1] This method was accepted as tentative by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part I.

[2] 1936 Book of A.S.T.M. Standards, Part I, p. 504.

NOTE.—The assumed densities of 7.5 and 7.7 in these methods are based on Eq. 2, which is commercially satisfactory for sheets of approximately 0.013 to 0.026 in. in thickness. Recognition is given to the linear Eqs. 1 and 2 on the basis that they represent the average straight line drawn through many test points obtained on commercial grades of silicon alloy steels for electrical purposes, of various silicon contents. Individual tests may show departures of various magnitudes from this average line which is given in equation form for general use and guidance.

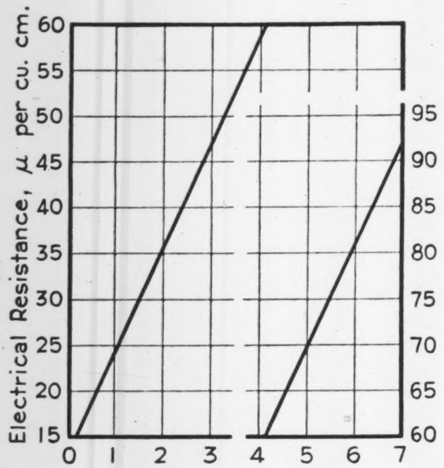

FIG. 1.—Silicon Content *versus* Electrical Resistivity of Commercial Grades of Silicon Alloy Steels for Electrical Purposes.

NOTE.—The linear equation for this graph is as follows:

$$R = 13.25 + (11.3 \times \text{silicon, per cent})$$

where R = resistance in microhm per cubic centimeter at approximately 20 C.

This equation is based on the density *versus* silicon content shown by the relation in Eq. 1. The equation is also based on the average line drawn through many test points obtained on commercial grades of silicon alloy steel for electrical purposes, of various silicon contents. Individual tests may show departures from this average line, which is shown in equation and graphical form, for general use and guidance. The intercept constant 13.25 for zero silicon does not usually apply to steels having silicon contents under about 0.15 per cent. As the metalloid content, including silicon, decreases to low values, the intercept constant decreases, approaching the value of about 10.7.

New Figure.—Add as a new Fig. 2 the accompanying Fig. 1, renumbering the present Figs. 2 and 3 as Figs. 3 and 4.

Transformers which are used in connection with electronic tubes often have their cores subjected to a combination of alternating and direct magnetizing forces. Under these conditions, the cores exhibit different effective permeabilities and core losses than is the case when they are subjected to alternating-current magnetizing forces alone. Subcommittee IV is undertaking an extensive investigation of test methods under these conditions and it is thought desirable to have suitable nomenclature to designate these so-called incremental properties. Subcommittee I on Nomenclature and Definitions has accordingly prepared the definitions given below which the committee recommends be accepted for publication as a tentative revision of the Standard Definitions of Terms, with Units and Symbols, Relating to Magnetic Testing (A 127 – 36):[3]

Polarizing Magnetizing Force, H_d.—The algebraic mean of the maximum and minimum values of an oscillating magnetizing force.

NOTE.—Where the time function of the alternating component of the oscillating magnetizing force is symmetrical, the polarizing magnetizing force is proportional to the direct current as indicated by a d'Arsonval type ammeter.

Incremental Magnetizing Force, H_Δ.—One-half the algebraic difference of the maximum and minimum values of an oscillating magnetizing force.

$$\Delta H = 2H_\Delta$$

Polarized Induction, B_d.—The algebraic mean of the limits of the instantaneous inductions in a magnetic material subjected to the simultaneous application of a polarizing and an incremental magnetizing force.

Incremental Induction, B_Δ.—One-half of the algebraic difference between the limits of the instantaneous inductions in a magnetic material subjected to the simultaneous application of a polarizing and an incremental magnetizing force. The whole difference or twice the incremental induction is indicated by the symbol ΔB. Thus:

$$\Delta B = 2B_\Delta$$

Incremental Core Loss, P_Δ.—The core loss in a magnetic material occurring when the material is subjected to the simultaneous application of a polarizing and an incremental magnetizing force.

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[3] 1936 Book of A.S.T.M. Standards, Part I, p. 518.

III. Adoption as Standard of Tentative Revision of Standard

The committee recommends that the definition of the term weber and the revised definitions for magnetic induction and intrinsic induction, published last year[4] as a tentative revision of the Standard Definitions of Terms, with Units and Symbols, Relating to Magnetic Testing (A 127 – 36), be approved for reference to letter ballot of the Society for adoption as standard.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. New Tentative Standard			
Method of Test for Measuring Lamination Factor of Steel (A 34 – 39 T)	17	0	1
II. Revisions of Standards			
Methods of Test for Magnetic Properties of Iron and Steel (A 34 – 38), immediate adoption	17	0	1
Definitions of Terms, with Units and Symbols, Relating to Magnetic Testing (A 127 – 36), five new definitions	17	0	1
III. Adoption as Standard of Tentative Revision of Standard			
Definitions of Terms, with Units and Symbols, Relating to Magnetic Testing (A 127 – 36), one new and two revised definitions	16	0	2

IV. Tentative Standard Continued as Tentative

It is recommended that the Tentative Method of Test for Measuring Interlamination Resistance of Steel (A 34 – 38 T) be retained in the tentative status for another year. Only one minor change has been suggested to date and this will be held for action pending the committee's recommendation to adopt the method as standard.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 25 members; 18 members returned their ballots, with the results shown in Table I.

Activities of Subcommittees

Subcommittee I on Nomenclature and Definitions (W. J. Shackelton, chairman).—Since no adverse comments have been received concerning the definition of the term weber and the revised definitions for magnetic induction and intrinsic induction, which were published as tentative last year, they are being recommended for adoption as standard.

Some adverse criticisms of suggested definitions concerning incremental magnetic properties were received from members of the committee. These definitions as modified are now being submitted to the Society for publication as tentative. It is believed that these definitions should be made available, since considerable experimental work in this field is being started immediately by Subcommittee IV.

Subcommittee III on Direct Current Test Methods (B. M. Smith, chairman).—Two meetings of this subcommittee were held during the past year. The chief activity has been in connection with round-robin tests of high coercive force permanent magnet steel bars of the Alnico type. Differences obtained by various observers with different kinds of apparatus are greater than desirable, particularly with reference to coercive force, and no satisfactory explanation is at present available. Samples have been sent to England to the Metropolitan Vickers Co. and to the National Physical Laboratory for a further check. No test recommendations will be made until the cause of these discrepancies has been found and the differences reduced.

Subcommittee IV on Alternating Current Test Methods (J. P. Barton, chairman).—Three meetings of this subcommittee have been held during the past year. A method for testing lamination factor of steel has been under consideration for some time and after some modification, is being offered to the Society for publication as tentative.

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1318 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1684.

While it is known that scale-free silicon alloy steel has a density higher than the 7.7 and 7.5 g. per cu. cm. values assumed in connection with magnetic testing, by far the majority of the committee members felt that these values should be retained, although occasionally values of over 100 per cent lamination factor may be calculated. The above values still correspond very closely to the actual figures for silicon alloy steel sheet with a moderate amount of scale present. Formulas for information only, are being added, as described earlier in this report, to the Standard Methods of Test for Magnetic Properties of Iron and Steel (A 34 – 38) enabling those interested to determine the actual density as a function of silicon content both for scale-free material and for laminations with scale. In addition, there is given a curve and formula showing the relation between silicon content and resistivity.

Since there is a definite demand for a half-length Epstein sample both for core loss and permeability tests and such samples are actually in commercial use by certain companies for normal as well as low-induction tests, it has been decided to initiate a round-robin test of such samples with six laboratories cooperating. Samples of 1 kg. are proposed, 3 by 28 cm, half the test strips to be cut with the grain of rolling and half across the grain. A butt joint as well as a double lap joint is to be used. Core loss values are to be obtained at 60 cycles over the flux density range of 4000 to 16,000 gausses or higher. The alternating-current permeability values are to be obtained for approximately 10,000 gausses and higher. As a variety of turns on test coils will be found among those to be used in the cooperative studies, the results of this test should be of value in arriving at a standard method. For those normally using a sample of 0.5 kg., it has been suggested that both halves of the sample be tested.

In order to develop a method of test for magnetic properties under conditions of combined alternating and direct magnetization, a round-robin test is being started on approximately half-length Epstein samples with seven laboratories cooperating. These properties are of chief interest in connection with core materials for use in transformers connected to thermionic tubes. These incremental magnetic properties are also of interest with reference to transformers connected to rectifiers, three-legged reactors used for control purposes, and for a study of losses in the teeth of rotating machines.

These two sets of tests will probably occupy a year or more for completion.

This report has been submitted to letter ballot of the committee which consists of 25 members; 18 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

THOMAS SPOONER,
Chairman.

R. L. SANFORD,
Secretary.

REPORT OF COMMITTEE A-7

ON

MALLEABLE IRON CASTINGS

Committee A-7 on Malleable Iron Castings held two meetings during the year: in Atlantic City, N. J., on June 27, 1938, and in Columbus, Ohio, on March 7, 1939. At each meeting 11 members were present with 4 and 2 guests, respectively.

At the Atlantic City meeting the present officers were re-elected.

An effort has been made to obtain members for Committee A-7 who will take part in the work of the committee and who will represent companies which are active in the malleable industry. The following have been added to the committee during the year: W. A. Wecker, Assistant General Manager, McKinnon Industries, Ltd., St. Catharines, Ont., Canada, and Leon B. Thomas, Chief Metallurgist, Campbell, Wyant & Cannon Foundry Co., Muskegon Heights, Mich. Due to changes in occupation the following have resigned from the committee: I. M. Bregowsky, F. B. Riggan, and E. R. Torgler. The present membership of the committee now totals 37, of whom 16 are classified as producers, 12 as consumers, and 9 as general interest members; there are 2 consulting members.

Subcommittee II on Galvanizing Embrittlement (F. L. Wolf, chairman) is doing considerable work on this subject and it is expected that a report will be made by this subcommittee at the meeting of the committee to be held in Atlantic City during this annual meeting. Subcommittee IV on Specimens and Methods of Testing (H. A. Schwartz, chairman) expects to report on new work which it is undertaking. Subcommittee VII on Welding reports that a good deal of experimental work has been carried on during the year and it is expected that a report from this subcommittee will be forthcoming at the June meeting of the committee.

I. NEW TENTATIVE STANDARD

On the recommendation of Subcommittee VI on Pearlitic and Alloy Malleable Iron (H. M. Boylston, chairman), the committee is presenting for publication proposed Tentative Specifications for Pearlitic Malleable Iron Castings.[1]

II. ADOPTION OF TENTATIVE STANDARD AS STANDARD

On the recommendation of Subcommittee III on Cupola Malleable Iron (R. E. Bryant, chairman), the committee recommends that the Tentative Specifications for Cupola Malleable Iron (A 197 – 36 T)[2] be approved for reference to letter ballot of the Society for adoption as standard.

At the suggestion of the Society's Committee E-10 on Standards, Committee A-7 gave consideration to the necessity of including a certification clause in Specifications A 197 and to the wording that is employed. Both Subcommittee III and Committee A-7 in general considered that the present form of the certification clause is best suited for the desired purpose and recommended that no change be made in the wording of this paragraph.

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[1] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 665 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 252.

III. STANDARD CONTINUED WITHOUT REVISION

In order to determine whether the Standard Specifications for Malleable Iron Castings (A 47 – 33) are in accord with present practice, comment and suggestions for revision were solicited from the members of the committee. No changes were received; accordingly on the recommendation of Subcommittee V on Air Furnace and Electric Malleable Iron (W. P. Putnam, chairman) the committee recommends that Specifications A 47 be continued as standard without revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 37 members; 34 members returned their ballots, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Spec. for Pearlitic Malleable Iron Castings	29	1	4
II. ADOPTION OF TENTATIVE STANDARD AS STANDARD			
Spec. for Cupola Malleable Iron (A 197 - 36 T)	32	0	2

This report has been submitted to letter ballot of the committee which consists of 37 members; 33 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

E. K. SMITH,
Chairman.

H. A. SCHWARTZ,
Secretary.

REPORT OF COMMITTEE A-9
ON
FERRO-ALLOYS

Committee A-9 held a meeting during the 1938 annual meeting of the Society, on June 29, 1938, in Atlantic City, N. J., and also at this annual meeting, on June 27, 1939.

Subcommittee I on Specifications (E. A. Lucas, chairman) continued by personal contact and correspondence further revision of the tentative specifications presented last year in an endeavor to bring the specification values in line with commercial practice and custom. The recommendations affecting these tentative standards are given later in this report.

Subcommittee I further reported progress in the preparation of specifications for ferroboron, ferrotitanium, and silicon manganese, which it hopes to have ready for presentation next year.

Of general interest at the meeting of the committee held during this annual meeting was a short discussion on the advisability of preparing specifications for molybdenum compounds other than calcium molybdate. While calcium molybdate has been the chief medium of molybdenum additions, new developments in the use of molybdenum briquets and molybdenum oxides as additive agents have already caused a shift of calcium molybdate from first to third place in volume. The committee felt that while there is a pronounced tendency to change from calcium salt, many consumers whose practice is based on molybdate may continue its use. Therefore, Subcommittee I will follow the trend during the next year and be prepared to submit at the 1940 annual meeting either new specifications for these products or modify the present Specifications for Molybdenum Salts and Compounds (A 146) to include briquets and oxides.

I. REVISION OF TENTATIVE STANDARDS

The committee recommends that the two tentative specifications listed below be revised as follows and continued as tentative, and that the withdrawal of the two existing standard specifications[1] be approved at this time:

Tentative Specifications for Spiegeleisen (A 98 – 38 T):[2]

Section 3 (a).—Change the table of chemical requirements from its present form to read as follows:

	Grade A	Grade B	Grade C
Manganese, per cent	16.00 to 19.00	19.00 to 21.00	25.00 to 28.00
Carbon, max., per cent	6.50	6.50	6.50
Phosphorus, max., per cent	0.25	0.25	0.25
Sulfur, max., per cent	0.05	0.05	0.05
Silicon	[a]	[a]	[a]

[a] May be obtained containing silicon as follows: 1.00 per cent, max.; 1.00 to 2.00 per cent; 2.00 to 3.00 per cent; and 3.50 to 4.50 per cent.

Section 4.—Change to read as follows by the addition of the italicized words:

4. Spiegeleisen shall be packed in sound containers, *or shipped in bulk*, in such manner that none of the metal is lost in shipment.

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[1] 1936 Book of A.S.T.M. Standards, Part I, pp. 503, 492.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 615, 621 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 256, 262.

Tentative Specifications for Ferrochromium (A 101 – 38 T):[2]

Section 1.—Change from its present form: namely,

> 1. These specifications cover ferrochromium in four grades as follows: High-carbon ferrochromium, Grade A; Low-carbon ferrochromium, Grades B, C, and D.

to read as follows:

> 1. These specifications cover two grades of ferrochromium designated: High-carbon, and Low-carbon.

Section 2.—Change to read as follows by the omission of the words in brackets:

> 2. (*a*) High-Carbon Ferrochromium [Grade A material] shall be furnished to size as specified.
>
> (*b*) Low-Carbon Ferrochromium [Material of Grades B, C and D] shall be crushed to the specified size and mixed before packing, so that the quality in each package is uniform with the lot.

Section 3 (a).—Change the table of chemical requirements from its present form to read as follows:

	High Carbon	Low Carbon
Chromium, per cent	60.00 to 75.00	65.00 to 75.00
Carbon, per cent	4.00 to 8.00	2.00 max.[a]
Silicon, max., per cent	3.00	1.50

[a] May be obtained with the following maximum percentages of carbon: 2.00, 1.00, 0.50, 0.20, 0.15, 0.10, 0.06, and 0.04.

Section 4.—Change to read as follows by the addition of the italicized words:

> 4. Ferrochromium shall be packed in sound containers, *or shipped in bulk*, in such manner that none of the metal is lost in shipment.

TABLE I.—CHEMICAL REQUIREMENTS OF FERROMANGANESE.

	Standard	Medium Carbon			Low Carbon	
		Grade A	Grade B	Grade C	Grade A	Grade B
Manganese, per cent	78.00 to 82.00	80.00 to 85.00	80.00 to 85.00	80.00 to 85.00	80.00 to 85.00	80.00 to 85.00
Carbon, max., per cent	7.50	as specified[a]	as specified[a]	as specified[a]	as specified[b]	0.75
Phosphorus, max., per cent	0.35	0.35	0.35	0.35	0.35	0.35
Sulfur, max., per cent.	0.05	0.05	0.05	0.05	0.05	0.05
Silicon, max., per cent	1.25	1.25	1.50	2.50	1.25	7.00

[a] Medium-carbon material may be obtained with the following maximum percentages of carbon: 3.00, 2.00, 1.50, and 1.00.

[b] Grade A low-carbon material may be obtained with the following maximum percentages of carbon: 0.75, 0.50, 0.30, 0.15, and 0.10.

TABLE II.—CHEMICAL REQUIREMENTS OF FERROSILICON.

	Grade A	Grade B	Grade C	Grade D	Grade E	Grade F	Grade G
Silicon, per cent	90 to 95.00	80 to 90.00	72 to 79.00	47 to 52.00	25 to 30.00	14 to 18.00	8 to 14.00
Carbon, max., per cent	0.15	0.15	0.15	0.15	0.50	1.50	1.50
Sulfur, max., per cent	0.04	0.04	0.04	0.04	0.04	0.06	0.06
Phosphorus, max., per cent	0.05	0.05	0.05	0.05	0.06	0.15	0.15

II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following six tentative specifications be approved for reference to letter ballot of the Society for adoption as standard, with revisions in four of the specifications, as indicated in detail below, and also that the withdrawal of the seven existing standard specifications[3] be approved at this time:

Tentative Specifications for Ferromanganese (A 99 – 38 T):[4]

Section 3 (a).—Change the table of chemical requirements from its present form to read as shown in the accompanying Table I.

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[3] 1936 Book of A.S.T.M. Standards, Part I, pp. 493 to 502, incl.

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 617 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 258.

Section 4.—Change to read as follows by the addition of the italicized words:

> 4. Ferromanganese shall be packed in sound containers, *or shipped in bulk,* in such manner that none of the metal is lost in shipment.

Tentative Specifications for Ferrosilicon (A 100 – 38 T):[5]

Section 1.—Change from its present form: namely,

> 1. These specifications cover ferrosilicon in six grades, as follows: Grades A, B, C, D, E, and F.

to read as follows:

> 1. These specifications cover seven grades of ferrosilicon designated A, B, C, D, E, F, and G.

Section 3 (a).—Change the table of chemical requirements from its present form to read as shown in the accompanying Table II.

Section 4.—Change to read as follows by the addition of the italicized words:

> 4. Ferrosilicon shall be packed in sound containers, *or shipped in bulk,* in such manner that none of the metal is lost in shipment.

Tentative Specifications for Ferromolybdenum (A 132 – 38 T):[6]

Section 3 (a).—In the table of chemical requirements interchange the chemical composition of Grade A and Grade B.

Tentative Specifications for Ferrotungsten (A 144 – 38 T):[7]

Section 3 (a).—In the table of chemical requirements change the maximum phosphorus content from "0.05 per cent" to read "0.06 per cent."

Tentative Specifications for Ferrovanadium (A 102 – 38 T), and for Molybdenum Salts and Compounds (A 146 – 38 T):[8]

These two tentative specifications are recommended for adoption as standard without revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 27 members; 25 members returned their ballots, with the results shown in Table III.

Respectfully submitted on behalf of the committee,

CHARLES MCKNIGHT,
Chairman.

C. M. LOEB, JR.,
Secretary.

TABLE III.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF TENTATIVE STANDARDS			
Spec. for Spiegeleisen (A 98 – 38 T), replacing A 98 – 27	23	1	1
Spec. for Ferrochromium (A 101 – 38 T), replacing A 101 – 27	24	1	0
II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for Ferromanganese (A 99 – 38 T), as revised, replacing A 99 – 27	25	0	0
Spec. for Ferrosilicon (A 100 – 38 T), as revised, replacing A 100 – 27	25	0	0
Spec. for Ferromolybdenum (A 132 – 38 T), as revised, replacing A 132 – 34 and A 145 – 34	25	0	0
Spec. for Ferrotungsten (A 144 – 38 T), as revised, replacing A 144 – 34	24	1	0
Spec. for Ferrovanadium (A 102 – 38 T), replacing A 102 – 27	25	0	0
Spec. for Molybdenum Salts and Compounds (A 146 – 38 T), replacing A 146 – 34	25	0	0

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[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 619 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 260.

[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 625 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 266.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 627 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 268.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 623, 629 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 264, 270.

REPORT OF COMMITTEE A-10

ON

IRON-CHROMIUM, IRON-CHROMIUM-NICKEL AND RELATED ALLOYS

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys held one meeting during the year: in Columbus, Ohio, on March 9, 1939, during the spring group meetings of the Society.

Several changes in committee personnel have occurred, resulting in a present membership of 75, of whom 32 are classified as producers, 30 as consumers, and 13 as general interest members.

Specifications for bars, tubing, and wire have been delayed for various reasons while specifications for cast and flat products, which have had a tentative status for several years, are being recommended for adoption as standard with editorial improvements and a regrouping into three broad classifications, with a separate specification for the 18 per cent chromium, 8 per cent nickel type (A 198), as mentioned later in this report.

I. REVISIONS OF STANDARDS

The committee recommends for immediate adoption, revisions in the following specifications, and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society:

Standard Specifications for Corrosion-Resisting Chromium Steels (Sheet, Strip, and Plate) (A 176 - 38):[1]

Section 14 (a).—Since No. 3 Finish for cold-rolled strip is no longer manufactured by the steel producer omit this finish and the explanatory note which read as follows:

> *No. 3 Finish.*—Annealed, pickled, mechanically cleaned or buffed without the use of abrasives.
>
> No. 3. For parts requiring medium amount of deep drawing, for rolling and molding operations. This strip has a bright surface and requires very little polishing to finish.

Standard Specifications for High-Strength Corrosion-Resisting Chromium-Nickel Steels (Sheet and Strip) (A 177 - 38):[1]

Section 4.—Change the manganese content from "0.60 per cent, max." to read "1.50 per cent, max."

II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative specifications be approved for reference to letter ballot of the Society for adoption as standard with a revision in one of the specifications as indicated below:

Tentative Specifications for:

12 per cent Chromium Steel Castings (A 168 - 35 T),[2] 19 per cent Chromium Steel Castings (A 169 - 35 T),[2] and 28 per cent Chromium Steel Castings (A 170 - 35 T)[2] con-

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[1] 1938 Supplement to Book of A.S.T.M. Standards, pp. 52, 59.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, pp. 623, 627, 631, 635, 640, 645, 649, 653 (1935); also 1938 Book of A.S.T.M. Tentative Standards, pp. 151, 156, 160, 170, 175, 180, 184, 188.

solidated into Specifications for Chromium Alloy-Steel Castings;[3]

24 per cent Chromium, 12 per cent Nickel Alloy Steel Castings (A 171 – 35 T),[2] 25 per cent Chromium, 20 per cent Nickel Alloy Steel Castings (A 172 – 35 T),[2] and 28 per cent Chromium, 9 per cent Nickel Alloy Steel Castings (A 173 – 35 T)[2] consolidated into Specifications for Chromium-Nickel Alloy-Steel Castings;[3]

20 per cent Nickel, 9 per cent Chromium Alloy Steel Castings (A 174 – 35 T),[2] and 35 per cent Nickel, 15 per cent Chromium Alloy Steel Castings (A 175 – 35 T)[2] consolidated into Specifications for Nickel-Chromium Alloy-Steel Castings;[3]

20 per cent Chromium, 9 per cent Nickel Alloy Steel Castings (A 198 – 36 T),[4] with editorial changes, and

Corrosion-Resisting Chromium-Nickel Steels (Sheet, Strip, and Plate) (A 167 – 38 T),[5] revised as follows:

Section 4.—Change the table of chemical composition requirements from its present form to read as shown in the accompanying Table I.

Section 7.—Change the table of physical properties from its present form to read as shown in the accompanying Table II.

TABLE I.—CHEMICAL REQUIREMENTS.

	Type Number	Carbon, per cent	Manganese, max., per cent	Phosphorus, max., per cent	Sulfur, max., per cent	Silicon, per cent	Chromium, min., per cent	Nickel, min., per cent
Grade 1	301	0.08 to 0.20	1.50	0.035	0.030	0.75 max.	16.00	7.00
Grade 2	302	0.08 to 0.20	1.50	0.035	0.030	0.75 max.	18.00	8.00
Grade 3	304	0.08 max.	1.50	0.035	0.030	0.75 max.	18.00	8.00
Grade 4	308	0.08 max.	1.50	0.035	0.030	0.75 max.	19.00	10.00
Grade 5[a]	321	0.10 max.	1.50	0.035	0.030	0.75 max.	18.00	8.00
Grade 6[b]	347	0.10 max.	1.50	0.035	0.030	0.75 max.	18.00	8.00
Grade 7	302 B	0.08 to 0.20	1.50	0.035	0.030	2.00 min.	18.00	8.00
Grade 8	309	0.08 to 0.20	2.00	0.035	0.030	3.50 max.	22.00	12.00
Grade 9	309 S	0.08 max.	2.00	0.035	0.030	3.50 max.	22.00	12.00
Grade 10	310	0.25 max.	2.00	0.035	0.030	2.00 max.	24.00	19.00
Grade 11[c]	316	0.08 max.	2.00	0.035	0.030	0.75 max.	16.00	10.00
Grade 12[d]	317	0.08 max.	2.00	0.035	0.030	0.75 max.	18.00	10.00

[a] Grade 5 shall have a minimum titanium content of four times the carbon content.
[b] Grade 6 shall have a minimum columbium content of ten times the carbon content.
[c] Grade 11 shall have a molybdenum content of 2.00 to 3.00 per cent.
[d] Grade 12 shall have a molybdenum content of 3.00 to 4.00 per cent.

TABLE II.—PHYSICAL TEST REQUIREMENTS.

	Tensile Strength, min., psi.	Yield Point, min., psi.	Elongation in 2 in., min., per cent	Hardness		Cold Bend, deg.
				Brinell, max.	Rockwell (B Scale, 100-kg. load, $\frac{1}{16}$-in. ball), max.	
Grade 1	75 000	30 000	40.0	202	88	180
Grade 2	75 000	30 000	40.0	202	88	180
Grade 3	75 000	30 000	40.0	202	88	180
Grade 4	75 000	30 000	40.0	202	88	180
Grade 5	75 000	30 000	40.0	202	88	180
Grade 6	75 000	30 000	40.0	202	88	180
Grade 7	75 000	30 000	40.0	217	95	180
Grade 8	75 000	30 000	40.0	217	95	180
Grade 9	75 000	30 000	40.0	217	95	180
Grade 10	75 000	30 000	40.0	217	95	180
Grade 11	75 000	30 000	40.0	217	95	180
Grade 12	75 000	30 000	40.0	217	95	180

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 75 members; 48 members returned their ballots, with the results shown in Table III.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Classification of Data (E. F. Cone, chairman; Russell

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[3] These specifications, as consolidated, were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 639 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 164.

[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 593 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 142.

Franks, secretary).—Substantial progress in the work of this subcommittee has been made, the data collected by its eight subgroups are being compiled, following which they will be referred to letter ballot of Committee A-10 for approval for publication. It was decided to exclude nickel-base alloys and first publish information on the more important stainless steels. Publication can be expected later in the year.

Subcommittee IV on Methods of Corrosion Testing (E. S. Taylerson, chairman).—A special subcommittee, consisting of F. L. LaQue and H. W. Schmidt, has prepared a "Guide for Plant Corrosion Tests," which was approved by Committee A-10 at its March meeting. Certain minor modifications have been made and the Guide in its latest form is presented herewith as information only.[6] Following a review by other interested committees, namely, Committee A-5 on Corrosion of Iron and Steel and Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys, it will be presented to the Society through Committee E-10 on Standards later in the year for publication as a tentative recommended practice.[6]

TABLE III.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISIONS OF STANDARDS			
Spec. for Corrosion-Resisting Chromium Steels (Sheet, Strip, and Plate) (A 176 - 38), immediate adoption	36	1	11
Spec. for High-Strength Corrosion-Resisting Chromium-Nickel Steels (Sheet and Strip) (A 177 - 38), immediate adoption	36	1	11
II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for 12 per cent Chromium Steel Castings (A 168 - 35 T)	35	0	13
Spec. for 19 per cent Chromium Steel Castings (A 169 - 35 T)	35	0	13
Spec. for 28 per cent Chromium Steel Castings (A 170 - 35 T)	35	0	13
Spec. for 24 per cent Chromium, 12 per cent Nickel Alloy Steel Castings (A 171 - 35 T)	36	1	11
Spec. for 25 per cent Chromium, 20 per cent Nickel Alloy Steel Castings (A 172 - 35 T)	36	1	11
Spec. for 28 per cent Chromium, 9 per cent Nickel Alloy Steel Castings (A 173 - 35 T)	36	1	11
Spec. for 20 per cent Nickel, 9 per cent Chromium Alloy Steel Castings (A 174 - 35 T)	37	0	11
Spec. for 35 per cent Nickel, 15 per cent Chromium Alloy Steel Castings (A 175 - 35 T)	37	0	11
Spec. for 20 per cent Chromium, 9 per cent Nickel Alloy Steel Castings (A 198 - 36 T)	34	0	14
Spec. for Corrosion-Resisting Chromium-Nickel Steels (Sheet, Strip, and Plate) (A 167 - 38 T), as revised	36	1	11

A preliminary draft of a liquid boiling test procedure has been found too general and will be revised to give more specific details concerning this type of test.

Tests on wire products, in cooperation with Committee A-5, are being continued and are reported on this year by that committee.[7]

Inspections, under the jurisdiction of this subcommittee of stainless steel in architectural use have been completed by the special subcommittee consisting of C. C. Snyder (chairman), V. N. Krivobok, H. J. Huester, F. H. Frankland, and J. A. Fouilhoux. These inspections were made at New York City, Philadelphia, and Atlantic City, several other members of the committee being present by invitation at one or more of the visits. The report of the subcommittee, with pertinent comment as to the condition of the various installations, processing details during manufacture, and suggestions to avoid difficulties during or after installation appears as Appendix I.

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[6] See Editorial Note, p. 196.

[7] See report of Committee A-5 on Corrosion of Iron and Steel, p. 99.

Subcommittee V on Mechanical Tests (V. N. Krivobok, chairman).—This subcommittee is continuing its study of elastic properties of the 18 per cent chromium, 8 per cent nickel types of steel, and some data under various types of loading have been secured. It is hoped that a progress report can be made shortly.

Subcommittee VI on Metallography (Russell Franks, chairman).—This subcommittee has completed the microscopic examination of the 18 per cent chromium, 8 per cent nickel types of steel after various heat treatments using various etching reagents for revealing carbides. The following laboratories cooperated in this work:

U. S. Navy Department, Munhall, Pa.,
International Nickel Co., Research Laboratories, Bayonne, N. J.,
National Bureau of Standards, Washington, D. C.,
U. S. Steel Corp., Research Laboratories, Kearny, N. J.,
General Electric Co., Schenectady, N. Y., and
Union Carbide and Carbon Research Laboratories, Niagara Falls, N. Y.

The report on the data obtained has been approved by Subcommittee VI and appears as Appendix II. The various methods of etching for carbides and the remarks in connection therewith should be of interest to all concerned with this type of steel. This report has been submitted to letter ballot of Committee A-10 which consists of 75 members; 00 members returned their ballots, of whom 00 have voted affirmatively, 0 negatively, and 00 members marked their ballots "not voting."

Subcommittee VII on Welding (L. C. Bibber, chairman).—While continuing to cooperate with the Welding Research Committee on problems involving the welding of materials falling within the scope of Committee A-10, this subcommittee has been relatively inactive during the past year. A re-examination of the subcommittee's activities will be held during the June meeting.

Subcommittee VIII on Specifications for Wrought Products (F. B. Foley, chairman).—While there is still no demand from consuming interests for specifications covering bars and forgings, there has been a specific request to prepare specifications covering spring wire of 18 per cent chromium, 8 per cent nickel steel. It seems likely that the subcommittee will be reorganized to cover wire products and steps taken to prepare such specifications.

Subcommittee IX on Specifications for Flat Products (C. C. Snyder, chairman).—This subcommittee has reviewed the several specifications for flat products prepared by it and has approved minor changes in each, as mentioned earlier in this report. It is recommended that the Tentative Specifications for Corrosion-Resisting Chromium Nickel Steels (A 167 – 38 T) be adopted as standard, as revised, and that the revision of the Standard Specifications for Corrosion-Resisting Chromium Steels (A 176 – 38), and for High-Strength Corrosion-Resisting Chromium-Nickel Steels (A 177 – 38) be adopted immediately.

Subcommittee X on Specifications for Castings (W. J. Jeffries, chairman).—Several new members were added to this subcommittee at the March meeting. Consideration has been given to the various casting specifications and these have been consolidated into three broad groups, with the specification for the 18 per cent chromium, 8 per cent nickel type (A 198) being retained as a separate standard. The subcommittee has approved the adoption of the tentative specifications as standard as mentioned earlier in this report.

Research, under the auspices of the Alloy Steel Castings Group at Battelle Memorial Institute, is progressing. At the request of the committee, a paper describing a new type of test block, resulting from this work, is being presented at this annual meeting of the Society.[8]

Subcommittee XI on Specifications for Tubular Products (Newell Hamilton, chairman).—This subcommittee is unbalanced with respect to consumer members; consequently interest in the preparation of specifications has been lacking to some extent. A preliminary draft of specifications for 18 per cent chromium, 8 per cent nickel steel still tubes has been held in abeyance pending a correction of this condition and for the further reason that clarification is needed on certain questions arising with Subcommittee IX on Steel Tubing and Pipe of Committee A-1 on Steel. A discussion of the subcommittee's activities will be held at the June meeting.

This report has been submitted to letter ballot of the committee which consists of 75 members; 48 members returned their ballots, of whom 47 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

JEROME STRAUSS,
Chairman.

H. D. NEWELL,
Secretary.

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[8] O. E. Harder, "The Alloy Casting Research Institute Test Block for Heat-Resisting Alloys; Its History, Selection and Utilization," see p. 626.

EDITORIAL NOTE

Subsequent to the annual meeting Committee A-10 took action to submit the Guide for Conducting Plant Corrosion Tests, published as information with its report, as a Tentative Recommended Practice. This new tentative recommended practice was accepted on behalf of the Society by Committee E-10 on Standards on August 24, 1939, and appears in the 1939 Book of A.S.T.M. Standards, Part I, bearing the designation A 224 – 39 T.

APPENDIX I

REPORT OF SPECIAL SUBCOMMITTEE ON INSPECTION OF STAINLESS STEEL ARCHITECTURAL STRUCTURES

In order to obtain information on the behavior of the corrosion-resisting steels under conditions of actual service a special committee was appointed in 1937 to inspect several architectural installations of stainless steel. The special committee visited and examined the installations at the Chrysler and Empire State Buildings in New York City, the Philadelphia Saving Fund Society Building in Philadelphia, and several building fronts along the boardwalk at Atlantic City, N. J. The information obtained at these inspections is presented in this report.

Chrysler Building, New York City:

Visits were made to the Chrysler Building on December 9, and to the Empire State Building on December 10.

Arrangements had been made with the Superintendent of Maintenance of the Chrysler Building for the inspection and before inspecting the stainless steel, a general discussion of the situation was held.

The committee was told that the spire had not been cleaned since its erection in 1930. The gargoyles had been partially cleaned recently as part of a motion picture stunt but not as regular maintenance. The store fronts on the ground floor are cleaned every two months with a mixture of Italian pumice and whiting to remove traffic film. Every day the interior and exterior trim on the ground floor is dusted.

During a wind storm several years ago several sheets became loosened and were blown from the spire. This has been the only instance where there has been a breakage of the soldered points. The coping at the seventy-first floor has now been reinforced with a hold-down strip to prevent further loosening.

The Superintendent stated that he, as well as the building owners, are quite pleased with the results obtained with stainless steel. When the building was first opened, a rusty, spotted condition was noted on the revolving doors. Upon investigation it was learned that the ordinary steel work in the mechanism above the doors was not protected and rust was running down upon the stainless steel. This was corrected by painting the common steel parts.

The Superintendent receives letters from all over the world inquiring as to the condition of the stainless steel and in response he advises them that the stainless steel is working out excellently. The Superintendent also reported that corrosive conditions are very severe at the Chrysler Building due primarily to the heavy industrial atmosphere, and also to the sea atmosphere prevailing in the New York area, and in a minor degree to the stack discharges from the power plants located southeast of the building which occasionally are carried by the wind in the direction of the tower.

A visit to the seventy-first floor disclosed that the stainless steel was covered with a dark film. Upon rubbing with pumice and whiting, the film was easily removed, disclosing the original bright finish beneath.

Locations on two sides of the building were examined and revealed that although the metal had a darkened appearance, due to an accumulation of smoke and soot, this film was readily removed. All the joints and seams had been soldered and after soldering the flux was neutralized with soda. It was interesting to note that there was no corrosion as a result of the use of stray soldering fluxes, in fact, the metal directly adjacent to the soldered joints in many cases was brighter than the metal away from the joints.

There was no pitting of the metal, although several minute places were detected by a magnifying glass where there has been slight etching.

An inspection of the store fronts and revolving doors revealed them to be in excellent condition.

The material on the spire and coping is 18 per cent chromium, 8 per cent nickel stainless steel, No. 4 bright finish corresponding to stainless steel of grade No. 1, type No. 302, finish No. 4 conforming to the Tentative Specifications for Corrosion-Resisting Chromium-Nickel Steels (Sheet, Strip and Plate) (A 167 – 35 T) of the American Society for Testing Materials.[1]

Empire State Building, New York City:

The installation at the Empire State Building was inspected on December 10, 1937. The committee first consulted the Building Superintendent who stated that the stainless steel spandrels were of 18 per cent chromium, 8 per cent nickel steel,[2] No. 6 Tampico finish and extended from the sixth floor to the observation tower. He also stated that the stainless steel had not been cleaned or polished since he had been placed in charge of the building in May, 1931.

The committee examined the stainless steel mullions and vertical strips at the sixth floor offset and at the seventy-second floor offset. There was no rusting or staining, but the same dark film as was noticeable at the Chrysler Building was apparent. Removal of the film with whiting and pumice disclosed the original finish of the metal. There was some slight etching of the metal at the sixth floor offset which is believed to be the condition that was noted during erection of the building and was due to contamination from building filth, such as, plaster, cinders, cement and rust from iron work which caused contact corrosion. Following a washing down of the building with pumice and ammonia water, the etched condition has proceeded no further. This cleaning operation was performed before completion of the building and was a regular step in procedure.

At the seventy-second floor, the film was not so heavy as at the sixth floor, the metal appearing much brighter. The slight etching noticed at the sixth floor was not discernible. It has been reported recently by unidentified parties that the 34th Street side of the building is showing rust. There is a reddish color on the metal which can be easily seen at the seventy-second floor. Investigation showed the reddish color is coming from a red lead caulking compound which is running out from between the overlapping joints. Removal of the caulking compound disclosed excellent appearance beneath.

Analysis of Stainless Steel Sheets.—There were approximately 500 tons of 18 per cent chromium, 8 per cent nickel polished stainless steel sheets applied on the Empire State Building. The analysis of the nearly 200 heats of steel used showed the following range in composition:

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 667 (1935); also 1935 Book of A.S.T.M. Tentative Standards, p. 193.

[2] Tentative Specifications for Corrosion-Resisting Chromium-Nickel Steels (Sheet, Strip and Plate) (A 167 – 35 T), grade No. 1, type 302, No. 6 finish, of the American Society for Testing Materials. *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 667 (1935); also 1935 Book of A.S.T.M. Tentative Standards, p. 193.

Carbon, per cent	0.066– 0.13
Manganese, per cent	0.31 – 0.50
Phosphorus, per cent	0.011– 0.026
Sulfur, per cent	0.017– 0.023
Silicon, per cent	0.22 – 0.45
Chromium, per cent	17.51 –18.98
Nickel, per cent	8.10 – 9.40

Processing Treatment.—The sheets, following hot rolling, annealing (1950 F. air cool) and pickling, were polished in the following manner to obtain the distinctive No. 6 Tampico finish:

(*1*) Ground with 80-mesh grit dry
(*2*) Polished with 100-mesh grit grease
(*3*) Polished with 120-mesh grit grease
(*4*) Polished with 150-mesh grit grease
(*5*) Tampico brushing with compound of lime, whiting, and oil.

Following polishing, all sheets were passivated in a warm nitric acid (20 per cent) bath, then formed into panel sections on brakes. During the forming operation, the polished surface was protected with lubricants and cellophane. The lubricant was removed with kerosine and the entire panel passivated in warm nitric acid solution. Before the material was released from the mill a 100-hr. salt spray test was made on coupons taken from each sheet. After erection on the building, the panels were washed down with pumice and water to remove building filth that had collected during erection of the building.

The following analysis of the atmosphere of New York City made by the Bell Telephone Laboratories was received in a report from J. R. Townsend, Materials Standards Engineer:

Carbon dioxide content	approx. 0.04 per cent
Sulfur dioxide content	0.8 to 2 parts per million
Chlorides	trace

From the above, it will be seen that the New York City atmosphere is a moderate industrial atmosphere, differing from other industrial atmospheres because of the trace of the chlorides present in the air.

An analysis of dirty coating scraped off the Chrysler Building was made by C. M. Sterne, Chief Engineer, Metropolitan Refining Co., Inc., who submitted the following information on the results of the tests:

> "Analysis of a sample of the dirty coating which the writer scraped from the stainless steel sheets of the Chrysler Building above the gargoyles consisted of carbon (oily soot), 52.1 per cent; sulfates, 29.7 per cent; Silica, 10.1 per cent; the remaining 8 per cent was mainly organic matter and undetermined matter, and, as I recall, contained some chloride and some iron.
>
> As you can see from the analysis, the greater portion of this dirty coating was undoubtedly from the products of combustion.

Philadelphia Saving Fund Society Building, Philadelphia:

The Philadelphia Saving Fund Society Building in Philadelphia, Pa., was inspected in June, 1938. In this building stainless steel of the 18 per cent chromium, 8 per cent nickel type, finish Nos. 4 and 6, has been used as store fronts, marquees, panels in entry ways, elevator panels, escalator trim, facing of bank vaults, safety deposit rooms, and facing for boxes, and kitchen equipment in the bank kitchen. The building was opened in May, 1932, and at the time of the inspection was 6 yr. old.

The manager of the P.S.F.S. Building told the committee that he was quite pleased with the appearance of the metal and the small amount of maintenance work required to keep it in first class condition. The stainless steel on the exterior of the building is cleaned at the same time the windows are washed, which is every several days. Ivory soap and water is used on the stainless steel, no polishing or hard rubbing being required.

The inspection of the exterior metal, which is essentially a store front, revealed it to be in excellent condition, no staining, no rusting, or pitting, being visible. An examination of the metal applied in the interior of the building revealed the same excellent condition.

The manager pointed out that a number of panels over the elevator entrance, when received from the fabricator, had a brownish appearance. The panels were passivated with a nitric acid solution on the job. This treatment did not entirely remove the brownish tinge, some very slight discoloration still being visible on close examination. The manager stated that the fabricator could offer no satisfactory explanation for the appearance of the panels other than that the discoloration was caused by unsatisfactory packing and shipping conditions.

To avoid recurrence of similar conditions, it is recommended that polishing operations be performed with iron-free compounds and that following polishing, the material should be wiped free of grease with whiting.

Since none of the committee members were familiar with the installation, no further comment can be made.

Atlantic City Boardwalk:

At Atlantic City, N. J., the following storefronts along the boardwalk were inspected in June, 1938:

Du Pont Exhibit Building
M. Gettleman
Apollo Theatre
Regis Restaurant

Stainless steel is applied on the above building fronts as window molding, marquees, signs, doors, entry way panels, and trim. Atmospheric conditions are quite severe due to the close proximity to the ocean and the salt spray which is ever present.

On all of the storefronts where the stainless steel is cleaned regularly, the metal is in excellent condition. At a height above which the window washer can reach and where the metal receives no cleaning, small pits and some rusting was observed. The depth of the pits was of no consequence and there were no signs of perforation of the metal.

The storefront of M. Gettleman, installed in 1933, included both 18 per cent chromium steel and 18 per cent chromium, 8 per cent nickel steel. The 18 per cent chromium had discolored quickly and has been replaced in part with 18 per cent chromium, 8 per cent nickel steel. The committee was able to identify the remaining 18 per cent chromium with a magnet.

The manager of M. Gettleman stated that since 18 per cent chromium, 8 per cent nickel stainless steel had been installed, he need no longer be concerned about the appearance of his storefront.

The Apollo Theatre has a large installation of 18 per cent chromium, 8 per cent nickel stainless steel which is given an over-all cleaning regularly. No indication of pitting or staining was apparent. This installation was made in 1931.

It was the consensus of opinion of the committee that conditions at Atlantic City were more conducive to corrosion and tarnishing of metals than at either New York City or Philadelphia, because of the salt spray which is constantly blowing on the building fronts. Evaporation permits salt to precipitate, which will, if not removed within a reasonable period of time, result in appreciable staining and some shallow pitting of 18 per cent chromium steel and 18 per cent chromium, 8 per cent nickel steel. From the above, 18 per cent chromium, 8 per cent nickel steel appears distinctly preferable. To insure satisfactory service from the 18 per cent chromium, 8 per cent nickel stainless steel in exposures of this nature, the metal should be cleaned regularly.

Recommended Practice for Decorative Installations:

The following recommendations are presented for the selection, fabrication, erection, and cleaning of stainless steel for exterior architectural applications.

In the development of a satisfactory stainless steel storefront, care and judgment should be exercised in selecting the proper type of material, surface finish, design and application. Surfaces should be vertical wherever possible to permit easy draining, thus avoiding stagnant pools. All areas should be readily accessible so that cleaning is easy.

As a result of many tests and much experimental work, storefronts and molding sections are produced from sheets or strip, or both. If sheets, a No. 4 finish or No. 7 is generally used, which is satisfactory since the sheets are ground and polished at the mill. If this surface is not disturbed during fabrication, it is quite suitable for service. Particular care should be taken in processing. Forming dies should be covered with paper or cloth to protest the polished surface against scratching or iron contamination. If strip is used in a rolled molding, as is usually the case, the section must be refinished by brushing and buffing or polishing and buffing to produce a surface clean and bright for outside exposure. If improperly finished or if iron-bearing compounds are used, surface discoloration usually results. Generally speaking, a good brushing with a Tampico brush and grit stick, followed by buffing to a high color and lustre, will produce a very satisfactory finish. Buffing alone should not be depended upon.

In some cases, passivation in nitric acid before polishing is desirable, especially in perforated sections where the brush or buff will not reach all surfaces.

In designing a storefront, drainage and cleaning are very important. If the surfaces are mainly vertical, whether plain or fancy, they will be exposed to both rain and sunshine and will, therefore, be subject to natural washing, draining, and drying. This will do some cleaning and is highly desirable, especially in well elevated areas where frequent cleaning is impossible. Recessed areas will not benefit by such washing, but will tend to collect dirt and may suffer some corrosive attack under subsequent wet and dry conditions. The corrosion is due entirely to electrolytic action set up in small concentration cells where dirt or other foreign matter is permitted to lodge and wet and dry conditions exist. If such recessed areas are necessary, it would be advisable to enamel the inner surfaces, which would not only offset this condition to a large extent, but would also offer a contrast to the bright, gleaming outer surfaces, which very often may be highly desirable. Broad flat areas, such as those under marquees, where subject to moisture, condensate and gases from the atmosphere and not benefited by natural washing should be given proper care or such design should be avoided.

Particular attention should be given to designing sections so that they will be readily accessible for easy cleaning. It is of utmost importance that storefronts or moldings be frequently cleaned to maintain their brilliance. Highly polished and buffed surfaces should be used. Dull or pickled finishes should not be employed as they will tend to collect dirt more easily and present an unsightly appearance, just as will a dirty window, possibly starting corrosion.

Erection of the stainless sections should be done with the same degree of care and attention as would be given any other similar product made of brass or bronze. It should not be scratched or smeared with cement, plaster, or other foreign matter. After erection, all sections should be thoroughly washed down with whiting, whiting and fine pumice or Bon Ami and ammonia water to remove any and all dirt, finger marks, etc., accumulated during installation. After washing, it should be rinsed with clean water and dried with a clean cloth or chamois.

From this point on, if previous processing has been satisfactory, the maintenance of a beautiful front is entirely dependent on subsequent cleaning. Stainless steel sections should be washed regularly along with the windows, about every week or two. In general, plain water or ammonia water and a cloth will be sufficient. It would be best, however, to use some light cleanser such as Bon Ami or whiting. Along the seacoast and in some industrial districts where the atmosphere is contaminated with salt, dirt and sulfur dioxide, cleaning about three or four times a year with pumice added to the whiting may be necessary to remove the entire scum or deposit. This can best be determined for the individual installation after several regular cleanings.

Frequent and proper cleaning cannot be too strongly stressed.

There is no doubt that stainless steel of the correct type, when designed, fabricated, erected and maintained properly, as evidenced by experience over the past 10 yr., will give a good account of itself and present its original, bright, lustrous appearance indefinitely.

Respectfully submitted on behalf of the special subcommittee,

C. C. SNYDER, *chairman*
V. N. KRIVOBOK
F. H. FRANKLAND
H. J. HUESTER, and
J. A. FOUILHOUX

APPENDIX II

REPORT ON METALLOGRAPHIC EXAMINATION OF 18 PER CENT CHROMIUM, 8 PER CENT NICKEL STEELS

Subcommittee VI on Metallography

Two heats of austenitic 18 per cent chromium, 8 per cent nickel steels were sent to cooperating laboratories for study. The purpose of the study was to determine the nature of the material that is precipitated at the grain boundaries when an austenitic steel is given a heat treatment that renders it susceptible to intergranular corrosion. The two wrought steels investigated had the following compositions:

	Heat No. 1	*Heat No. 2*
Carbon, per cent	0.065	0.098
Manganese, per cent	0.43	0.39
Silicon, per cent	0.40	0.56
Chromium, per cent	18.15	18.00
Nickel, per cent	8.89	9.79

Samples of each of these steels were annealed and then heat treated for 1 week at the temperatures 550, 650, 750, and 850 C. They were then submitted to several metallographers who were requested to use their preferred method of etching and to submit photomicrographs of the structures revealed. The magnifications requested were 100 and 750 diameters. The cooperating metallographers were:

- G. A. Holderness and Lt. Com. W. S. Kurtz, U. S. Navy
- J. W. Carey, International Nickel Co.
- G. A. Ellinger and H. S. Rawdon, National Bureau of Standards
- J. R. Vilella, U. S. Steel Research Laboratories
- W. D. Forgeng, Union Carbide and Carbon Research Laboratories

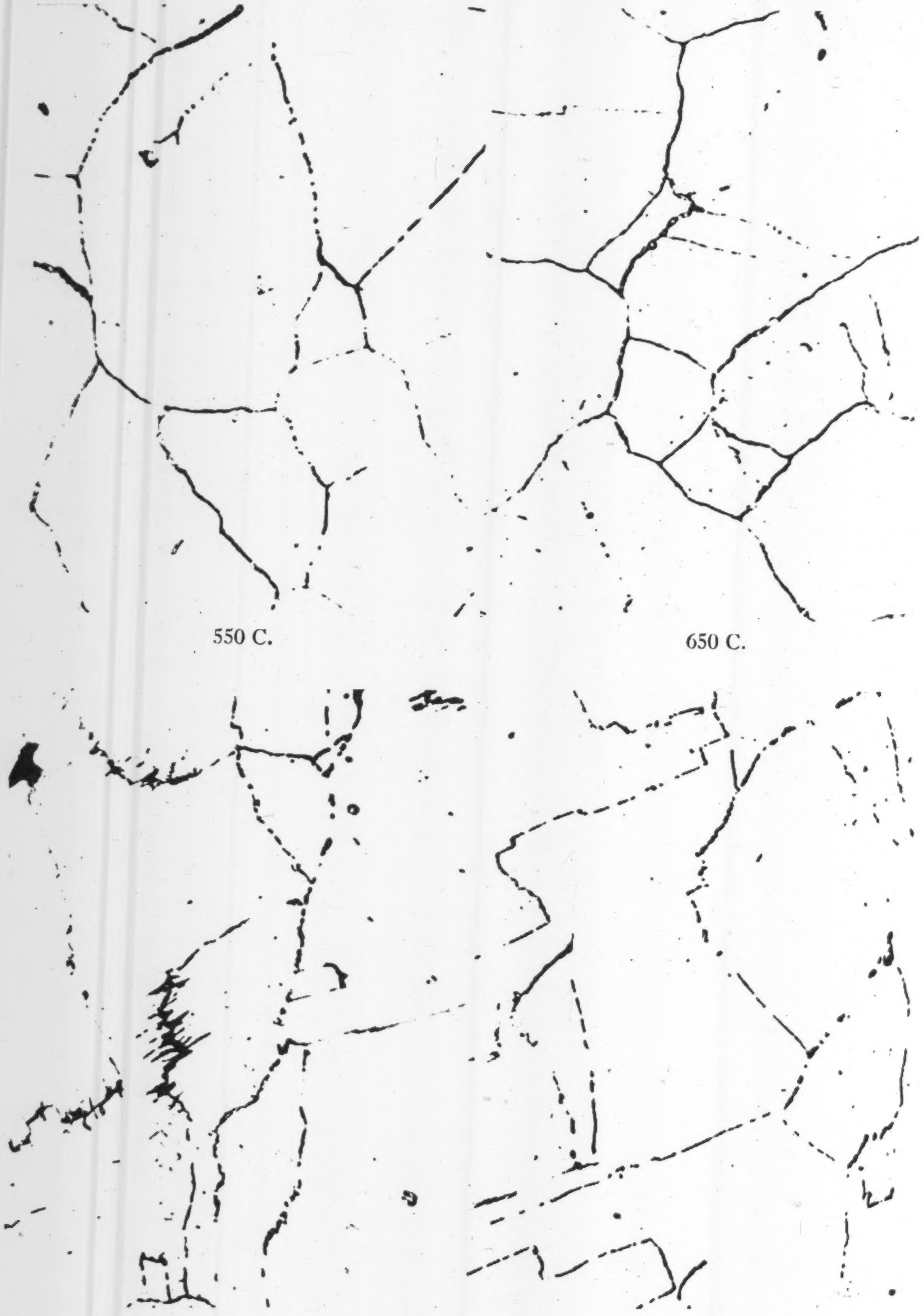
The etching reagents in Table I were employed for the development of the structures in the photomicrographs submitted by the cooperating laboratories:

TABLE I.—ETCHING REAGENTS.

Reagent	Conditions	Laboratory	Code Letter
$HClO_4$ (5 per cent), electrolytic	Not stated	Navy	D
Oxalic acid, electrolytic	6 v., 10 to 40 sec.	International Nickel	J
Aqua regia and glycerol	Repolished and re-etched several times	U. S. Steel	S
Oxalic acid (10 per cent)	10, 40, 70, and 100 sec.	Bur. of Stds.	R
Oxalic acid (10 per cent)	6 v., 15 sec.	UC & C Res. Labs.	T
Alcoholic HCl (10 per cent)	10 min.	UC & C Res. Labs.	T

Laboratory R also investigated the action of the following reagents upon the specimens from heat No. 1, which had been heated at 550 and 750 C. respectively:

- HNO_3 (10 per cent) in alcohol, electrolytic, 30 sec.
- Saturated solution of picric acid in alcohol, electrolytic, 30 sec.



550 C.

650 C.

750 C.

850 C.

FIG. 1.—Laboratory D. Heat No. 1 Material Etched (Electrolytic) in Perchloric Acid (5 per cent) (× 750).

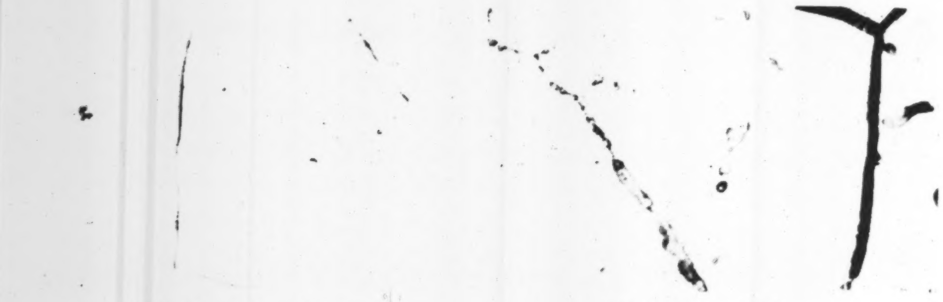
- NH_4OH (10 per cent) in water, electrolytic, 30 sec.
- Na_2CO_3 (10 per cent) in water, electrolytic, 30 sec.
- Ammonium citrate (10 per cent) in water, electrolytic, 30 sec.
- $(NH_4)_2S_2O_8$ (10 per cent) in water, electrolytic, 20 sec.
- Glacial acetic acid (10 per cent) in water, electrolytic, 30 sec.
- One gram of pyrogallic acid in 20 ml. of NaOH (30 per cent), electrolytic, 30 sec.
- Alkaline sodium picrate, boiling, 10 min.
- NaCN (10 per cent) in water, electrolytic, 5 min.
- Oxalic acid (10 per cent) in water, 15 and 45 sec.

Each specimen was polished and etched progressively with each reagent. Laboratory R found that it was not possible to determine exactly the etching effect of each reagent. It was stated however that the 10 per cent solution of ammonium persulfate in water offered some possibilities as an etching reagent that was somewhat slower than

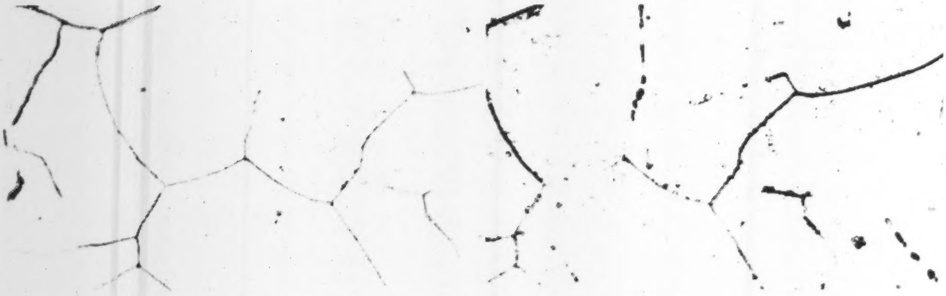
550 C. 650 C.

750 C. 850 C.

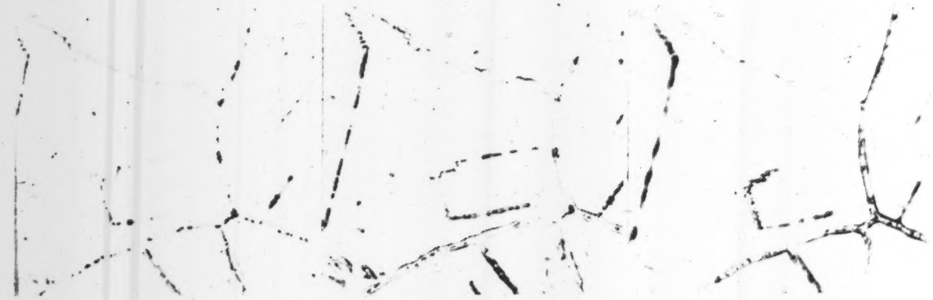
FIG. 2.—Laboratory J. Heat No. 1 Material Etched (Electrolytic) in Oxalic Acid (10 per cent) (× 750).



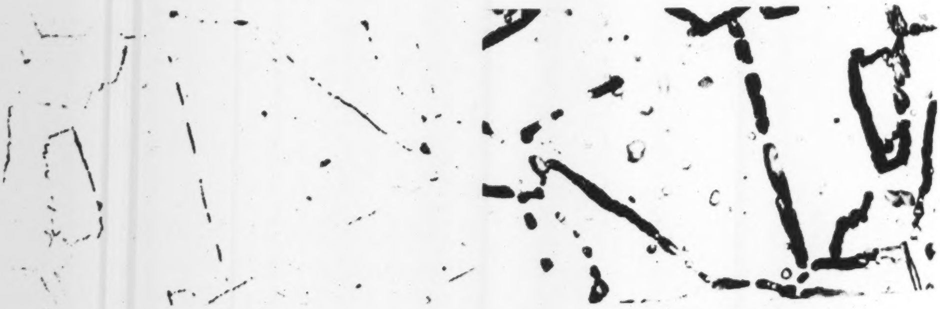
550 C., Etched 10 sec. 550 C., Etched 100 sec.



650 C., Etched 10 sec. 650 C., Etched 100 sec.



750 C., Etched 10 sec. 750 C., Etched 40 sec. 750 C., Etched 100 sec.

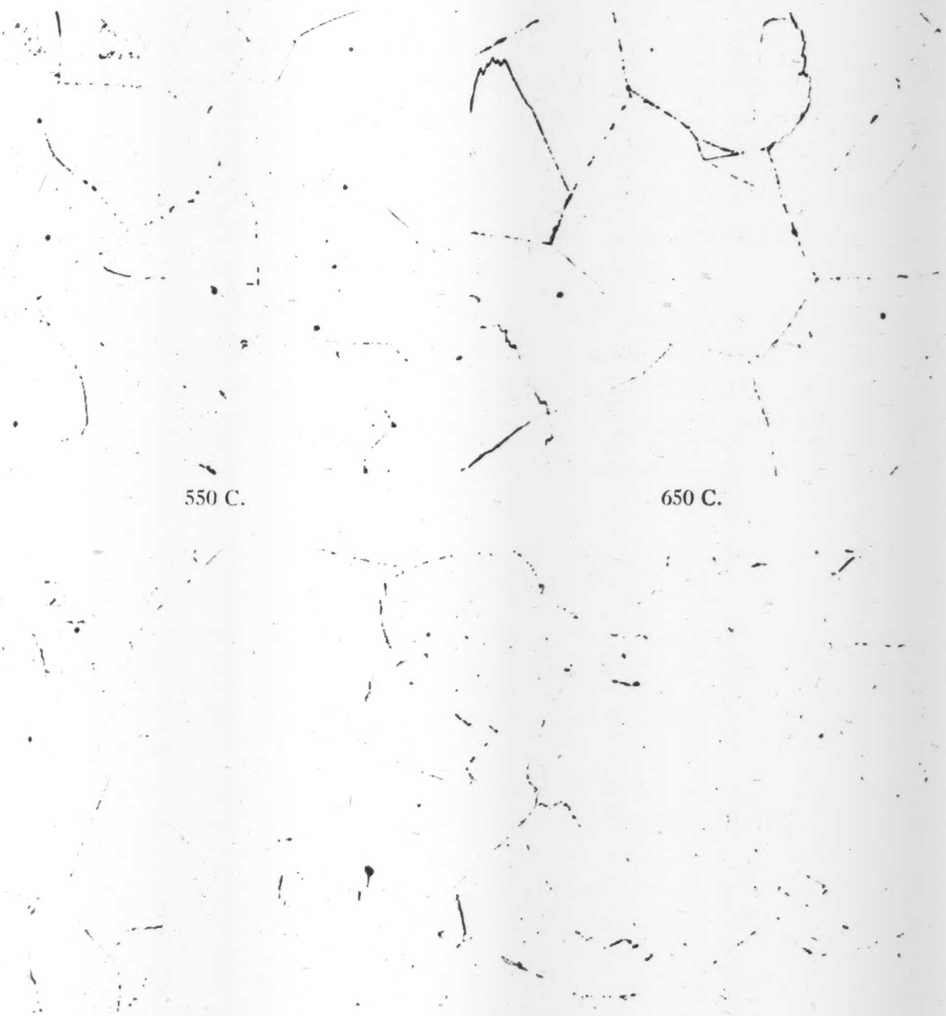


850 C., Etched 10 sec. 850 C., Etched 100 sec.

FIG. 3.—Laboratory R. Heat No. 1 Material Etched (Electrolytic) in Oxalic Acid (10 per cent) (× 750).

oxalic acid and more rapid than sodium cyanide.

The same specimens were again polished and a comparison was made between each of the reagents and ammonium persulfate.



550 C. 650 C.

750 C. 850 C.

FIG. 4.—Laboratory S. Heat No. 1 Material Etched in Aqua Regia and Glycerol (× 750).

The specimen that had been heated to 550 C. was not etched by HNO_3 (1 per cent), picric acid, sodium carbonate, or ammonium citrate. Ammonia and boiling alkaline sodium picrate each etched the specimen slightly.

Sodium cyanide, oxalic acid, and ammonium persulfate etched the specimen, each apparently etching the same spots and areas as the others. When etching lightly with oxalic acid and the persulfate, the results were identical with those obtained in a far greater time with sodium cyanide.

The specimen that had been heated at 750 C. was attacked by all reagents. Nitric acid (1 per cent) etched the specimen to a considerable extent, but did not reveal all of the features that were shown when etched with the persulfate. Twins or grain boundaries that did not contain localized constituents were not revealed by nitric acid.

Picric acid likewise etched certain features but not all. It is believed that picric and nitric acids reveal the same constituents.

550 C. 650 C.

750 C. 850 C.

FIG. 5.—Laboratory T. Heat No. 1 Material Etched (Electrolytic) in Oxalic Acid (10 per cent) (× 750).

Ammonium hydroxide, sodium carbonate, and ammonium citrate all etched the specimen, but as in the case of the acids above, not all features were revealed.

Very little etching resulted from the use of acetic acid solution. Each particle that was etched was later overetched when ammonium persulfate was used.

The solution of pyrogallic acid in sodium hydroxide has been recommended as a reagent for the etching of iron carbide. Normally, specimens are immersed in the cold solution for a period of 10 to 15 min. It is claimed that the results are exactly the same as those obtained with boiling alkaline sodium picrate. The specimen did not etch when used in this manner but did etch when used electrolytically. Apparently the same constituents were etched with the persulfate.

The specimen was slightly etched in localized areas when boiling sodium picrate was used.

The use of aqua regia in glycerol was advocated by laboratory S as an etching reagent because of its ability to disclose the individual carbide particles occurring at the grain boundaries. It was felt that the information disclosed by etching with that reagent was more significant than that obtained from reagents that attack the grain boundaries primarily but fail to disclose the gradual changes occurring in the size and distribution of the carbide particles.

In the photomicrographs of specimens etched electrolytically with oxalic acid by laboratories R and T it was noted that a duplex structure was apparent at the grain boundaries of the specimens treated at 750 C. This phenomenon was more evident in the low-carbon steel, heat No. 1. In view of this circumstance, the cooperating laboratories were requested to make a re-examination of that particular specimen.

The results of this re-examination seem to lead to the conclusion that the duplex structure can be detected in that specimen by means of the oxalic acid reagent. Laboratory S, however, doubted that the duplex structure was significant, since although the structure was revealed by the oxalic reagent, the results with aqua regia and glycerol were anomalous. It was found that while a similar condition was revealed by the latter reagent, this was made to disappear by polishing and re-etching several times.

Another significant result of the preliminary examination was the observation that at 550 C. precipitation occurred only at the main boundaries of the austenite grains. At 650 C. and 750 C., precipitation occurred at both the twin and grain boundaries, while at 850 C. the precipitation occurred chiefly in the twin boundaries and irregularly at the grain boundaries.

Photomicrographs of the low-carbon steel, heat No. 1, at a magnification of 750 diameters are reproduced in Figs. 1 to 5, inclusive. The photomicrographs at lower magnification as well as those of heat No. 2 showed no features that are not illustrated by the above figures, so it was felt that their reproduction was unnecessary.

The significance of the duplex structure at the grain boundaries of the sample heated to 750 C. is a matter of conjecture. The appearance is undoubtedly due to a rounding of the edges of the grains on either side of the carbide network. It is possible that this indicates the presence of an easily corrodible material in the vicinity of the carbides. This easily corrodible material is evidently present also in the samples heated at the lower temperatures but the plate-like carbides are not. In the 850 C. sample only the plate-like carbides are present. There is a correlation of these observations with the known susceptibility of heat-treated 18 per cent chromium, 8 per cent nickel steel to intergranular corrosion. Heating at temperatures from about 500 C. to 700 C. renders an 18 per cent chromium, 8 per cent nickel steel very susceptible to intergranular corrosion, but continued heating above the latter temperature decreases the susceptibility, and heating at 850 C. eventually stabilizes the steel completely.

Respectfully submitted on behalf of the subcommittee,

RUSSELL FRANKS,
Chairman.

REPORT OF THE RESEARCH COMMITTEE

ON

FATIGUE OF METALS

During the past year the Research Committee on Fatigue of Metals held a meeting in Columbus, Ohio, on March 6, 1939, during the spring meetings of A.S.T.M. committees. At that meeting there were discussions of the progress of the investigation of effect of type of testing machine on fatigue test results, of several proposed papers of interest to the committee to be presented at this annual meeting of the Society, and of fatigue test results of especial interest reported during the year.

The investigation of the effect of type of testing machine on fatigue test results, the program of which was outlined in the 1938 report of the committee,[1] is well under way. There has been some delay in receiving a supply of uniform material for the tests, but a supply of heat-treated alloy steel has been received and distributed to the cooperating laboratories which are to make tests. Test results have been received from two laboratories, and finished specimens of the metal are in the hands of all the laboratories but one. The supply of metal for tests of a low-alloy steel has not yet been received but is expected shortly.

Tests are being made on the following types of machines: (*1*) rotating-beam with two symmetrical loads (R. R. Moore type), (*2*) rotating-cantilever, (*3*) Haigh tension-compression, and (*4*) de Forest Rayflex vibratory type. The final finishing of all specimens is being done in one laboratory. The investigation has sufficient funds to continue its work during the next year on the modest scale originally outlined.

The committee calls attention to the following three papers on the subject of fatigue which are to be presented at this annual meeting of the Society:

"Fatigue Tests of Wire," by C. P. Wampler and N. J. Alleman,[2]

"Fatigue Strength of Machined Forgings 6 to 7 in. in Diameter," by O. J. Horger and H. R. Neifert,[3] and

"Fatigue Machines for Testing Structural Units," by R. L. Templin.[4]

During the year the committee has continued its cooperation with *Metals and Alloys* in the publication in that journal of abstracts of current articles on fatigue of metals.

This report has been submitted to letter ballot of the committee which consists of 20 members; 11 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. F. Moore,
Chairman.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 110 (1938).

[2] Published in ASTM Bulletin, No. 101, December, 1939, p. 13.

[3] See p. 723.

[4] See p. 711.

REPORT OF JOINT RESEARCH COMMITTEE

ON

EFFECT OF TEMPERATURE ON THE PROPERTIES OF METALS

PROGRESS REPORT TO THE SPONSOR SOCIETIES

Meetings:

During the past year, the Joint Research Committee on Effect of Temperature on the Properties of Metals, under the sponsorship of the American Society of Mechanical Engineers and the A.S.T.M., held one meeting: on November 18, 1938, in Columbus, Ohio. A second meeting of the committee will be held on June 28, 1939, in Atlantic City, N. J., prior to the presentation of this report at the annual meeting of the A.S.T.M.

The committee cooperated with the Applied Mechanics Division and the Power Division of the A.S.M.E. in sponsoring a session on December 6, 1938, in New York City, at the annual meeting of the A.S.M.E. Two reports, to be referred to later, were presented at that time.

Finances:

There appears in Table I a summary of the administration of funds during the past year, as of May 31, 1939.

Expenditures have been authorized and payments made to date on several research projects, as follows:

	Maximum Expenditure Authorized	Payment Made
Project No. 13 Low-Temperature Studies	$ 500.00	....
Project No. 18 Effect of Manufacturing Variables	2 500.00	$1 231.31

Organization and Membership:

There have been no changes in organization or membership since those recorded in the 1938 report of the committee.

High-Temperature Test Methods:

Although no criticisms nor comments have been received during the past year relative to the Tentative Method of Test for Short-Time High-Temperature Tension Tests of Metallic Materials (E 21 – 37 T), the committee recommends that the method be continued as tentative.

A complete revision of the Tentative Method of Test for Long-Time (Creep) High-Temperature Tension Tests of Metallic Materials (E 22 – 38 T) was submitted last year. The committee recommends that this method also be continued as tentative.

Research Projects:

There follows a summary of progress made in the various research projects during the year ending June, 1939.

Project No. 10 on Testing of Tubular Members at Elevated Temperatures, at the Massachusetts Institute of Technology (F. H. Norton, chairman).—A report[1] of this work was presented at the A.S.M.E. annual meeting on December 6, 1938, in New York City. The committee is now soliciting funds for the continuation of this research project.

Project No. 11 on Assembly and Inter-

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[1] "Creep in Tubular Pressure Vessels," by F. H. Norton, *Transactions*, Am. Soc. Mechanical Engrs., April (1939).

pretation of Available Creep Test Data at the University of Michigan (P. E. McKinney, chairman).—This project was completed in the summer of 1938 with the publication jointly by the sponsor societies of a Compilation of Available High-Temperature Creep Characteristics of Metals and Alloys, a bound volume of 848 pages. A total of 600 copies were bound, and at the time of this report these are practically all sold.

TABLE I.—SUMMARY OF RECEIPTS AND EXPENDITURES OF COMMITTEE FUNDS.

Balance shown in 1938 annual report			$6 069.32
	RECEIPTS		
September, 1938	Interest on funds	$ 83.60	
November, 1938	The Engineering Foundation	500.00	
January, 1939	The Engineering Foundation	500.00	
			$1 083.60
	EXPENDITURES		
1938			
May	Battelle Memorial Institute (Project No. 18)	$234.36	
	Battelle Memorial Institute (Project No. 12)	500.00	
			734.36
June	Battelle Memorial Institute (Project No. 18)	71.33	
	University of Michigan (Project No. 15)	600.00	
			671.33
September	Ogilvie Press (letterheads)	7.91	
	University of Michigan (Project No. 11)	664.39	
			672.30
December	A.S.T.M. (Publication "Creep Data")	500.00	
			500.00
1939			
February	Ogilvie Press (letterheads)	7.91	
	Battelle Memorial Institute (Project No. 18)	124.16	
			132.07
March	Battelle Memorial Institute (Project No. 18)	388.61	
	Mack Printing Co. (Preprints, Norton Paper)	11.00	
			399.61
May	Battelle Memorial Institute (Project No. 18)	246.09	
	Battelle Memorial Institute (Project No. 18)	472.45	
			718.54
			$3 828.21
Balance shown in 1938 report			$6 069.32
Cash receipts			1 083.60
			7 152.92
Expenditures			3 828.21
Balance on hand, May 31, 1939			$3 324.71

Project No. 13 on Investigations of the Properties of Metals at Low Temperatures (F. B. Foley, chairman).—This project committee has arranged a Round-Table Discussion of Effect of Subatmospheric Temperatures on the Properties of Metals, to be held at Atlantic City, N. J., on June 27, 1939, during the annual meeting of the A.S.T.M. The project committee will then prepare a brief on the subject, abstracting the round-table discussion, and include recommendations for research in this field.

Project No. 15 on Torsion-Creep Tests for Comparison with Tension-Creep Tests

(A. E. White, chairman).—This project was completed during the year, and a detailed report of work prepared by F. L. Everett and C. L. Clark appears in Appendix I.

Project No. 16 on Relaxation Tests (E. L. Robinson, chairman).—This project committee rendered a report in the form of a paper by E. L. Robinson entitled "The Resistance to Relaxation of Materials at High Temperatures," presented at the A.S.M.E. annual meeting on December 6, 1938. The paper will be published in an early issue of the A.S.M.E. *Transactions*.

Project No. 17 on Study of High-Temperature Life-Test Methods (A. E. White, chairman).—A progress report on this study was submitted last year.[2] Further work has been carried out during the year to determine whether the test method would reveal the effect of variations in grain size, and a detailed report of the work appears as Appendix II.

Project No. 18 on Study of Effects of Manufacturing Variables on the Creep Resistance of Steels (H. W. Gillett, chairman).—In the 1938 report[3] of the committee, it was shown that at temperatures of 750 to 950 F., medium-carbon steels showed better creep resistance with a coarse than with a fine austenitic grain size. The project has been continued this year, testing low-carbon steels made with different deoxidation practices. The work is still in progress and the data are incomplete.

The following materials are under test or available:

Silicon Ferrite,
Ingot iron, 0.016 per cent carbon—complete furnace practice known,
0.06 to 0.08 per cent carbon steel—rimmed, furnace practice known,
0.08 per cent carbon steel—silicon-killed, furnace practice known,
0.15 per cent carbon steel—aluminum-killed (2 lb. per ton), furnace practice known,
0.15 per cent carbon steel—silicon-aluminum-killed (1 lb. per ton), furnace practice known,
0.15 per cent carbon steel—silicon-killed, furnace practice known,
0.11 to 0.14 carbon-zirconium-treated steels, and
0.19 carbon British steel "E" (referred to in Appendix IV of Joint Committee report for 1937)[4].

It is planned to test all of these materials heat-treated to produce both fine and coarse austenitic grain. Tests in progress on the rimmed and killed steels have checked the findings of others that killed steel shows superior creep resistance to rimmed steels. The core of the rimmed steel is superior to the skin material. Variations in cooling rate have been made during the heat treatments of the 0.15 per cent carbon steel so as to produce different ferrite grain size and structure in material of the same austenitic grain size.

Room temperature tension and impact data are to be obtained on the steels given the various heat treatments used for the creep test specimens. The work is about half completed and it is hoped to present a report at the annual meeting of the A.S.M.E. in December, 1939.

Project No. 20 on Grain Size—A Summary of Terminology (R. H. Aborn, chairman).—Due to the very important positon that grain size has taken in the consideration of creep and other high-temperature characteristics of materials, the committee has noted the need for a primer on grain size and has assigned the work of preparation to a project committee. The work is well under way, and a report will be available later in the year.

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[2] A. E. White and C. L. Clark, "Report on Acceptability Tests for High-Temperature Characteristics," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 142 (1938).

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 149 (1938).

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 187 (1937).

Project No. 21 on Listing of High-Temperature Testing Apparatus (G. F. Jenks, chairman).—This project committee is preparing a list of all active high-temperature testing apparatus and methods in use in this country. This information will be of value to the committee and the sponsors in the further activities of the committee.

Project No. 22 on Correlation of All Test Data on K20 Steel (P. E. McKinney, chairman).—A great many high-temperature tests of various kinds have been made on this 0.35 per cent carbon steel. The committee believes that a useful purpose will be served by collecting all of these test results and attempting a correlation.

Project No. 23 on Effect of Temperature on Non-Ferrous Metals and Alloys (A. B. Bagsar, chairman).—Due to increased interest on the part of the copper and copper-alloy producers and consumers, the committee has appointed a project committee to determine the extent to which high-temperature investigations of non-ferrous metals may be in progress, the amount of data on such materials now available, to make recommendations as to procuring needed data, and to determine whether there are fundamental problems in which the committee should take direct action.

Correlation of Test Results.—The committee has appreciated the desirability of attempting correlation of test results from various projects, especially when the same, or essentially the same, material was used. Such attempts at correlation are best handled by an individual. A Correlation of Test Results for Various Types of High-Temperature Tests Carried out for the Joint Research Committee, prepared by E. A. Davis of the Westinghouse Research Laboratories, through the kind cooperation of Dr. A. Nadai, appears as Appendix III. The correlation uses test results from the work of Projects Nos. 10 and 15.

Respectfully submitted on behalf of the Joint Research Committee,

N. L. MOCHEL,
Chairman.
H. J. KERR,
Vice Chairman.

J. W. BOLTON,
Secretary.

APPENDIX I

REPORT ON TORSION CREEP TESTS FOR COMPARISON WITH TENSION CREEP TESTS ON A CARBON-MOLYBDENUM STEEL

(PROJECT NO. 15)

PREPARED BY F. L. EVERETT AND C. L. CLARK

During the June, 1936, meeting of the A.S.M.E.-A.S.T.M. Joint Research Committee on Effect of Temperature on the Properties of Metals, one of the authors, at the suggestion of A. E. White, presented a general program involving experiments in creep due to twist. An investigation had been made[1] in which thin-walled tube specimens were subjected to various constant torsional stresses over prolonged periods which indicated this method of creep testing could furnish important practical information.

Cases in design in which the loading is other than simple tension must be based on either experiments conducted under similar conditions of combined stress, temperature, and time, or a suitable theory must be applied to extrapolate the more abundant experimental information found from the tension test. The problem of designing a structure subjected to combined stresses of static type in which elastic conditions obtain may safely be said to be solved for the present by employing one of the various strength theories.[2] In practice various machine parts are subjected to complicated stresses and high temperature, such as tubes and piping under internal pressure and rotating disks and shafts. Some attention has been given this more complicated creep problem.[3, 4]

In a desire to lend assistance to furthering the study of creep under combined stresses, the Joint Committee authorized an expenditure of $1200 for creep experiments on a carbon-molybdenum steel under pure shear and under simple tension. The fundamental purpose of the investigation was to find what relationship might exist between the creep properties of a given material when subjected in one case to shear, as in a tube in torsion, and when subjected in the other case to direct tension in the usual cylindrical specimen. A program was developed in which a carbon-molybdenum steel whose properties and manufacturing history are given in Appendix A to this report[5] were to be investigated by means of testing eight specimens each in torsion creep and in tension creep. Two temperatures, 800 F. (427 C.) and 1050 F. (566 C.), and four different stresses for each temperature were to be used to determine the creep characteristics under each kind of creep.

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[1] F. L. Everett, "Strength of Materials Subjected to Shear at High Temperatures," *Transactions*, Am. Soc. Mechanical Engrs., APM-53-10 (1931).

[2] See a textbook on Strength of Materials. The theory of Huber, Mises, and Hencky appears useful for ductile materials.

[3] R. W. Bailey, "Design Aspects of Creep," paper read before Inst. Mechanical Engrs. (London), November 22, 1935. See abstract in *Transactions* Am. Soc. Mechanical Engrs., Vol. 58, p. A-1 (1936).

[4] C. R. Soderberg, "The Interpretation of Creep Tests for Machine Design," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 58, PP-58-15, p. 733 (1936).

[5] See p. 223.

TORSION CREEP INVESTIGATION

The specially designed equipment and the tubular specimens are described and illustrated in an earlier publication.[1] For ready reference, however, a brief discussion is given here. One of the two torsion creep units is shown in Fig. 1. The tubular specimen (Fig. 2) is contained in the electric furnace which has several taps for adjustment of temperature along the length of the specimen to a variation of within plus or minus 4 F. Thermocouples were attached at three locations on the wall of the tube specimen. Temperature control is effected by Foxboro apparatus. The lower end of the specimen is attached to the frame and the upper end is twisted by a constant torque supplied by attaching dead weights (below the picture) to wires applied to give a couple to a circular disk mounted at the top of the machine.

Angular strain—shear creep—was observed at 24-hr. intervals by one of two methods over a period of time—1000 hr. in the present experiments. A bar and a tube are each attached inside at two cross-sections of the specimen at 4 in. apart and brought down below the lower plate of the machine.

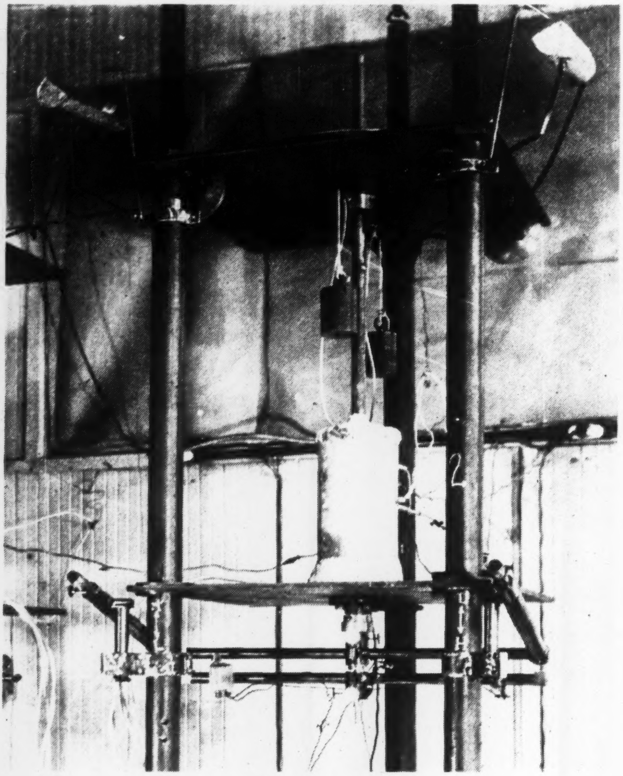


FIG. 1.—Torsion Creep Unit.

In the first method, light beams from two projectors cast marks on a curved graduated scale and the relative angle of twist and shear strain was determined as a function of the time. The sensitivity is about 8.12 × 10^{-6} shear strain so that a creep rate of 0.0338 per cent per 1000 hr. can be observed if readings are taken at 24-hr. intervals.

The more sensitive method employs an optical assembly consisting of a mirror which is rotated between two arms attached to the rod and tube mentioned above, telescopes, and illuminated scales. The sensitivity is approximately 33.8 × 10^{-9} shear strain and therefore a creep rate of 0.000141 per cent per 1000 hr. can be observed at 24-hr. intervals. The mirror system is about 240 times as sensitive as the projector method described above and is useful, therefore, in detecting creep where the rates are exceedingly small.

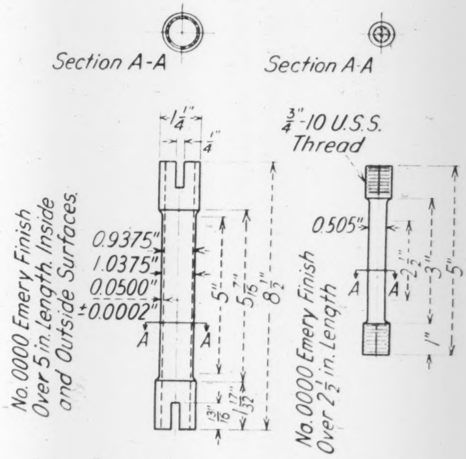
The torsion creep results are shown in Figs. 3 and 4. Part of the initial elastic and plastic strain in each case is not shown in the graphs. The results of the first test, using specimen No. 1, are somewhat erratic. A second experiment at the same stress and temperature, however, was performed, using specimen No. 10.

TENSION CREEP INVESTIGATION

The apparatus used for the tensile creep tests has been described many times in the literature. The stress is applied through a single lever and the deformation or creep is measured by an optical extensometer system sensitive to 2.8 × 10^{-6} in. per inch of the 2-in. gage length.

As in the torsion apparatus, the electric furnace is gap wound so that the current can be varied in three sections of the furnace. Three thermocouples are attached to the surface of the specimens, at the two gage marks and the center of the gage section, and the temperature variation along the gage section is within plus or minus 2 F. The temperature is controlled by a Foxboro temperature controller and the hot junction of the control thermocouple is placed in direct contact with the furnace winding. The temperature of the specimen was checked daily with a Leeds & Northrup semi-precision potentiometer.

Tensile creep tests were conducted on the committee's 0.50 per cent molybdenum steel at 800 and 1050 F. Four stresses were used at each temperature and each test was continued for at least 1000 hr. with deformation readings being taken at daily intervals.



(a) Torsion Creep Specimen.

(b) Tension Creep Specimen.

FIG. 2.—Specimens for High-Temperature Creep Tests.

TEST RESULTS

The time-deformation curves obtained from the torsion creep tests are given in Figs. 3 and 4 while those from the tension creep tests are given in Figs. 5 and 6. It should be noted that the sensitivity of the deformation scale of Fig. 5 has been greatly reduced. This was necessary because the stresses required to produce continuous creep over a 1000-hr. time period were of such magnitude that a large amount of plastic deformation occurred upon the application of these stresses. The resulting strain hardening which was produced,

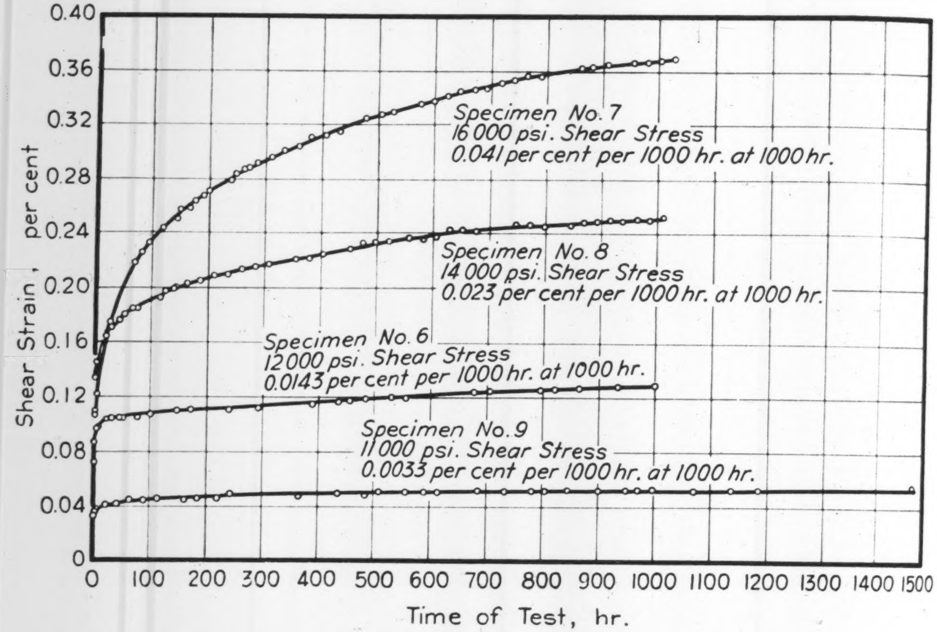


FIG. 3.—Torsion Creep of Carbon-Molybdenum Steel at 800 F.

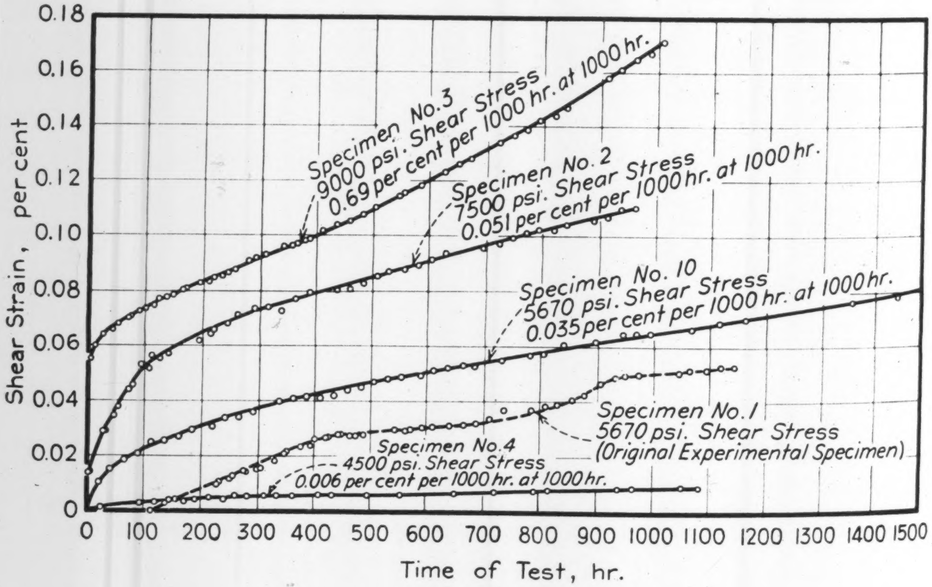


FIG. 4.—Torsion Creep of Carbon-Molybdenum Steel at 1050 F.

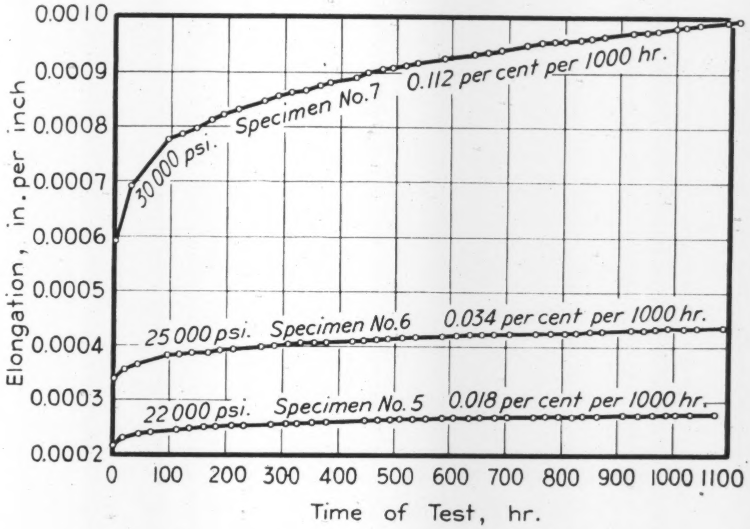


FIG. 5.—Time-Elongation Curves for 0.50 per cent Molybdenum Steel at 800 F.

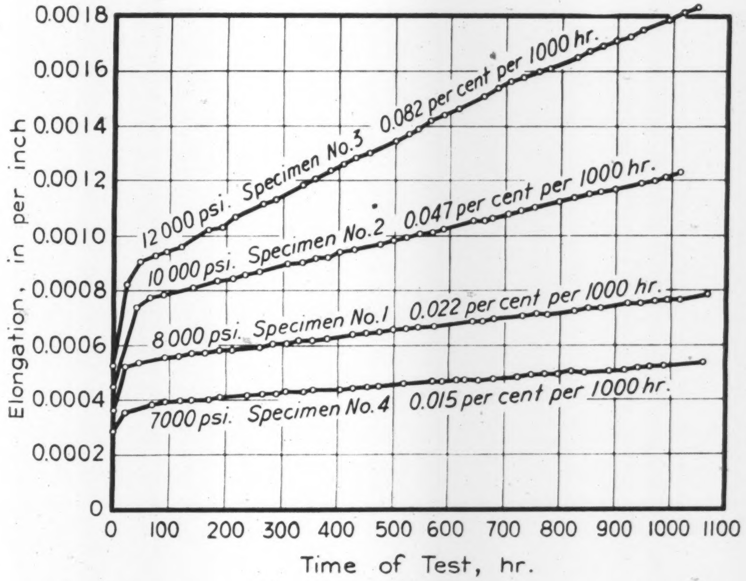


FIG. 6.—Time-Elongation Curves for 0.50 per cent Molybdenum Steel at 1050 F.

however, rapidly decreased the rate of plastic deformation.

In general, the stresses employed in the tensile creep tests were approximately twice those used in the torsion creep tests. For example, at 800 F. the stresses in the tension tests ranged from 20,000 to 30,000 psi. and those in the torsion tests from 11,000 to 16,000 psi. Likewise at 1050 F. the range in the corresponding stresses was from 7000 to 12,000 and from 4500 to 9000 psi., respectively.

In Fig. 7 the stresses and corresponding second stage creep rates from each of the two types of tests are plotted to logarithmic coordinates. On the basis of this relationship, the stresses corresponding to creep rates of 0.01 and 0.10 per cent per 1000 hr. can be determined. These stresses are given in Table I.

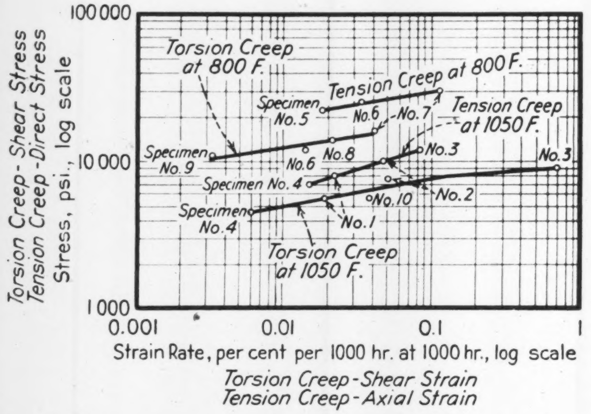


FIG. 7.—Torsion Creep and Tension Creep Carbon-Molybdenum Steel at 800 and 1050 F.

TABLE I.—TORSION CREEP AND TENSION CREEP CHARACTERISTICS OF 0.50 PER CENT MOLYBDENUM STEEL AT 800 AND 1050 F.

Temperature, deg. Fahr.	Type of Test	Stress for Designated Creep Rate, psi. (Rate = per cent per 1000 hr.)		Ratio, Torsion Creep to Tension Creep	
		At 0.01 per cent	At 0.10 per cent	At 0.01 per cent	At 0.10 per cent
800	Torsion	12 200	17 800	0.63	0.60
	Tension	19 250	29 750		
1050	Torsion	4 950	7 500	0.80	0.59
	Tension	6 200	12 800		

The stresses referred to in the table are maximum shear stresses in the case of the torsion experiments and maximum tensile stresses in the case of the tension experiments.

At each of the temperatures, this steel possesses a greater resistance to creep in tension than it does to creep in torsion. At 800 F. the ratio of the torsion creep strength to tension creep strength is of the order of 0.6 for both creep rates considered. This ratio is likewise of the same order of magnitude for the stresses corresponding to the higher creep rate at 1050 F. For the lower creep rate at this latter temperature, however, the ratio is approximately 0.8.

DISCUSSION OF RESULTS

It is generally found that with steels at room temperature the ratio of the yield point in shear to the yield point in tension is about 0.6. From the values of Table I it is likewise apparent that the same ratio applies for the stresses required for both creep rates at 800 F. and for the higher creep rate at 1050 F.

This in turn may imply that the mechanism of deformation at 800 F., as well as at 1050 F. under the more rapid deformation rates, is the same as that at room temperature.

This belief is substantiated by the fact that for this particular steel the strain hardening characteristics are pronounced at both room temperature and 800 F. While available evidence is not as ample, it is entirely possible that this same condition may also be true under rapid deformation rates at 1050 F. When strain hardening does occur, it is logical to assume that the deformation mechanism is the same and that deformation occurs by slipping along the crystallographic planes.

In the case of the stresses required for the lower creep rate at 1050 F., the ratio is 0.8 rather than 0.6. This in turn may imply that the mechanism of deformation is different under these conditions, thus indicating the plastic characteristics to predominate. Various theories have been advanced in the past claiming that plastic deformation occurs by the movement of crystals, rather than by slippage along crystallographic planes, and the results shown in Table I tend to support these theories. Additional data will have to be accumulated, however, before too definite conclusions can be drawn.

COMPARISON OF EXPERIMENTAL RESULTS WITH THEORIES

Some theoretical deductions have been made for the general case of creep under combined stresses.[3, 4, 6, 7] The need has been expressed for a better understanding of the fundamental relationship between the creep rate and the condition of the applied stress. Experimental creep data under various combinations of stress are required.

Based on the following theoretical analysis, some conclusions are obtained with respect to the results of the present creep investigation.

Assume[8]

$$\dot{e}_\infty = As^n \ldots\ldots\ldots\ldots\ldots (1)$$

$$s = \frac{1}{\sqrt{2}} \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \qquad (2)$$

or

$$s = \frac{1}{2^{\frac{1}{2}}} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{\frac{1}{2}}$$

$$\dot{e}_1 = \frac{\partial s}{\partial \sigma_1} \cdot \dot{e}_\infty \ldots\ldots\ldots\ldots\ldots (3)$$

Then

$$\dot{e}_1 = \frac{1}{2^{\frac{1}{2}}} \frac{1}{2} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{\frac{1}{2}} \left[2(\sigma_1 - \sigma_2) + 2(\sigma_3 - \sigma_1)(-1) \right] A \frac{1}{2^{n/2}} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{n/2}$$

or[9]

$$\dot{e}_1 = \frac{A}{2^{(n+1)/2}} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{\frac{n-1}{2}} \left[(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right]$$

For simple tension, $\sigma_1 = \sigma_1$; $\sigma_2 = \sigma_3 = 0$

$$\dot{e}_1 = \frac{A}{2^{(n+1)/2}} (2\sigma_1^2)^{(n-1)/2} (2\sigma_1)$$

$$\dot{e}_1 = A \frac{2^{(n-1)/2}}{2^{(n+1)/2}} \cdot 2 \cdot (\sigma_1^2)^{(n-1)/2} (\sigma_1)$$

$$\dot{e}_1 = A\sigma_1^n$$

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[6] C. R. Soderberg, "Plasticity and Creep in Machine Design," Stephen Timoshenko, Sixtieth Anniversary Volume, p. 197 (1938).

[7] A. Nadai, "On the Creep of Solids at Elevated Temperatures," *Journal of Applied Physics*, Vol. 8, p. 418 (1937).

[8] Equations 1, 2, and 3 are the usual equations variously employed by Bailey, Soderberg, Nadai, and others.

[9] The final equation is incorrectly presented (probably typesetter's error) in the discussion by J. Marin, *Transactions*, Am. Soc. Mechanical Engrs., Vol. 59, p. 510 (1937).

For pure shear, $\sigma_1 = -\sigma_2 ; \sigma_3 = 0$

$$\dot{e}_1 = \frac{A}{2^{(n+1)/2}} (6\sigma_1{}^2)^{(n-1)/2}(3\sigma_1)$$

$$\dot{e}_1 = A \frac{2^{(n-1)/2}}{2^{(n+1)/2}} \cdot 3^{(n-1)/2} \cdot 3 \cdot (\sigma_1{}^2)^{(n-1)/2} \cdot (\sigma_1)$$

$$\dot{e}_1 = A \frac{3^{(n+1)/2}}{2} \cdot \sigma_1{}^n$$

Since $\sigma_1 = \tau_{\max}$ and $\dot{\gamma} = \dfrac{\dot{e}_1}{2}$

$$\dot{\gamma} = A \cdot 3^{(n+1)/2} \tau^n_{\max}$$

For pure shear

$$\dot{\gamma} = A\ 3^{(n+1)/2} \tau^n_{\max}$$

$$\frac{\dot{\gamma}_1}{\dot{\gamma}_2} = \frac{A\ 3^{(n+1)/2} \tau^n_{\max 1}}{A\ 3^{(n+1)/2} \tau^n_{\max 2}}$$

$$\left(\frac{\tau_{\max 2}}{\tau_{\max 1}}\right)^n = \frac{\dot{\gamma}_2}{\dot{\gamma}_1}$$

$$n \log \frac{\tau_{\max 2}}{\tau_{\max 1}} = \log \frac{\dot{\gamma}_2}{\dot{\gamma}_1}$$

$$n = \frac{\log \dfrac{\dot{\gamma}_2}{\dot{\gamma}_1}}{\log \dfrac{\tau_{\max 2}}{\tau_{\max 1}}}$$

For simple tension

$$\dot{e}_1 = A\sigma_1{}^n$$

$$\frac{\dot{e}_{1_1}}{\dot{e}_{1_2}} = \frac{A\sigma^n_{1_1}}{A\sigma^n_{1_2}}$$

$$\left(\frac{\sigma_{1_2}}{\sigma_{1_1}}\right)^n = \frac{\dot{e}_{1_2}}{\dot{e}_{1_1}}$$

$$n \log \frac{\sigma_{1_2}}{\sigma_{1_1}} = \log \frac{\dot{e}_{1_2}}{\dot{e}_{1_1}}$$

$$n = \frac{\log \dfrac{\dot{e}_{1_2}}{\dot{e}_{1_1}}}{\log \dfrac{\sigma_{1_2}}{\sigma_{1_1}}}$$

EXPERIMENTAL DATA AND DERIVED VALUES OF n.

	Torsion Creep			Tension Creep		
	$\tau_{\max}$, psi.	$\dot{\gamma}$ per cent per 1000 hr.	n	σ_1, psi.	$\dot{e}_1$ per cent per 1000 hr.	n
800 F. . . .	11 000	0.0033		22 000	0.018	
			16.85			4.98
	12 000	0.0143		25 000	0.034	
			3.08			6.54
	14 000	0.023		30 000	0.112	
			4.33			
	16 000	0.041				
1050 F. . . .	4 500	0.006		7 000	0.015	
			8.18			2.87
	5 670	0.035		8 000	0.022	
			1.35			3.40
	7 500	0.051		10 000	0.047	
			14.29			3.05
	9 000	0.690		12 000	0.082	

The curves of Fig. 8 have been prepared by plotting σ_1 for the tension creep tests to twice the scale of the $\tau_{\max}$ for the torsion creep tests. The assumption is made that the values of n may be compared upon the basis of the maximum shear stress in each case. (For the case of simple tension $\sigma_1 = 2\tau_{\max}$).

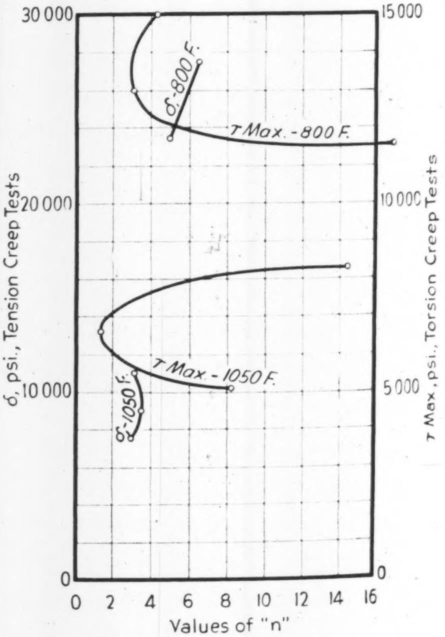


FIG. 8.—Values of "n" on Basis $\sigma_1 = 2\ \tau_{\max}$.

As may be seen from the plotted results for the torsion tests, the values of *n* appear to be greatest for both relatively low and high maximum shearing stresses, $\tau_{\max}$. The range of strain rates over which the tension creep tests were performed was smaller than for torsion and therefore, perhaps, a similar conclusion is not evident. The observation appears not illogical. Perhaps the value of *n* may be considered a constant only over a comparatively small range of stress.

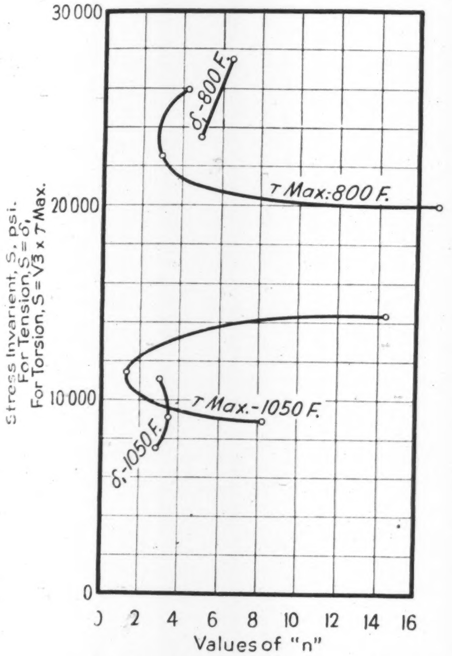
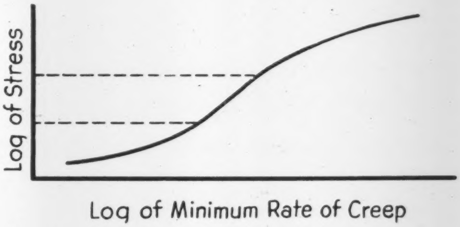


FIG. 9.—Values of "*n*" on Basis $\sigma_1 = \sqrt{3}\,\tau_{\max}$.



The slope of the assumed curve, shown above, is $1/n$.

One may observe in Fig. 8, that the values of *n* for the two types of creep tests are of the same order of magnitude on the selected basis of plotting in which $\sigma_1 = 2\tau_{\max}$.

The stress invariant, *s*, might be a more rational basis for comparing the relative values of *n*. For pure torsion, referring to Eq. 2, since $\sigma_1 = -\sigma_2 = \tau_{\max}$ and $\sigma_3 = 0$, the stress invariant, *s*, is found to be $\sqrt{3}\,\tau_{\max}$. For simple tension, since $\sigma_1 = \sigma_1$ and $\sigma_2 = \sigma_3 = 0$, the stress invariant is simply σ_1. Figure 9 was prepared on the basis of the stress invariant, *s*, plotted against the values of *n*, that is, $\sigma_1 = \sqrt{3}\,\tau_{\max}$. The agreement appears to be closer than for a plotting of $\sigma_1 = 2\tau_{\max}$ as shown in Fig. 8.

APPENDIX A

ANALYSIS AND MANUFACTURING HISTORY OF THE CARBON-MOLYBDENUM STEEL

The material was furnished by the Babcock & Wilcox Co. through Mr. H. J. Kerr, chairman of Project No. 19. Mr. J. B. Romer, Chief Chemist of the company, has given the following information as regards the material for Project No. 15:

Analysis of the Material:

	Heat No. 37239	
	Ladle Analysis	Check Analysis
Carbon, per cent	0.15	0.146
Manganese, per cent	0.53	0.54
Sulphur, per cent	0.016	0.018
Phosphorus, per cent	0.016	0.015
Silicon, per cent	0.21	0.21
Chromium, per cent	.....	.....
Molybdenum, per cent	0.56	0.53

Manufacturers Data:

Information pertinent to the manufacture of the steel described herein was supplied by the Crucible Steel Co. of America. The data given follows:

Type Melting Furnace—Open Hearth
Capacity—60 tons
Lining type—Basic
Ingot size—1½-in. round bars:
  21-in. square at top; 19-in. square at bottom; weight, 7000 lb.
  5-in. diameter billets:
    18-in. square at top; 16-in. square at bottom; weight, 5000 lb.
Location of Ingot Cut—Bars for creep tests taken from middle cut.

Heat Treatment:

The material was annealed in a car-type gas fired annealing furnace. The annealing treatment was as follows:

Heat to 1350 F., hold 1 hr., furnace cool 50 F. per hour to 1100 F., remove and cool in still air.

Brinell Tests:

Brinell tests after the above heat treatment gave values as follows: 5-in. round billets—131.

Distribution of Material:

1 piece tube 4½ in. in outside diameter by ¾ in. wall by 3 ft. long, to F. L. Everett, University of Michigan. (This material was not called for in the program and is still on hand.)

1 piece billet 5-in. diameter by 1 ft. 6 in. long, to F. L. Everett. (This piece was received at the University of Michigan cut in two lengths, from which torsion and tension creep specimens were machined as described in Fig. 2.)

Material from this same heat was also supplied on other projects to:
H. W. Gillett, Battelle Memorial Institute
C. L. Clark, University of Michigan
G. W. Wright, General Electric Co.
H. D. Newell, Babcock & Wilcox Tube Co.

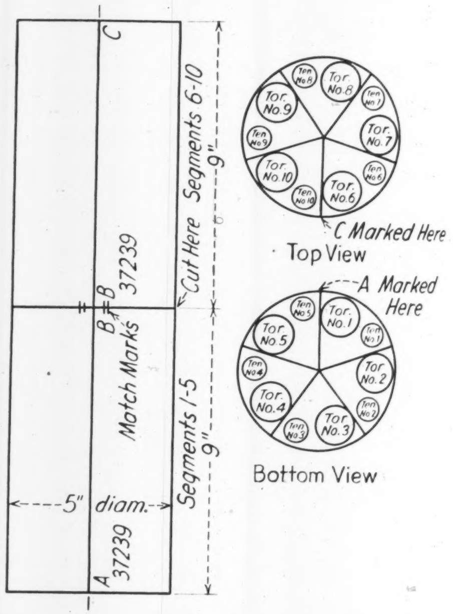

C
Segments 6-10
9"
Cut Here
37239
B
B
Match Marks
Segments 1-5
9"
5" diam.
A
37239
Tor. No. 8
Ten No. 8
Ten No. 7
Tor. No. 7
Ten No. 6
Tor. No. 6
Ten No. 10
Tor. No. 10
Ten No. 9
Tor. No. 9
C Marked Here
Top View
A Marked Here
Tor. No. 1
Ten No. 1
Tor No. 2
Ten No. 2
Tor No. 3
Ten No. 3
Tor. No. 4
Ten No. 4
Tor. No. 5
Ten No. 5
Bottom View

FIG. 10.—Location and Numbering of Specimens Used in High-Temperature Creep Tests.

F. H. Norton, Massachusetts Institute of Technology

In Fig. 10 is shown the manner in which the torsion and tension creep specimens were located in the billet received from the Babcock & Wilcox Co.

APPENDIX II

REPORT ON FURTHER EXPERIMENTS WITH A PROPOSED ACCEPTANCE TEST: EFFECT OF GRAIN SIZE

(PROJECT NO. 17)

PREPARED BY C. L. CLARK AND A. E. WHITE

A report[1] was presented before the American Society for Testing Materials in 1938 on the effects of manufacturing variables on the creep resistance of steels. The chief variable considered in this study was the austenitic grain size and, on the basis of 500-hr. creep tests, it was found that for each of the 13 steels considered the coarse-grained austenitic steels possessed a lower creep rate, that is, a greater creep strength, than did the corresponding fine-grained steels at the temperatures employed.

A report[2] was likewise presented which indicated that short-time rupture tests offered a possibility of rapidly classifying steels of the same type with respect to their relative order of creep strength. On the basis of this work, however, too definite conclusions were not permissible as only five steels were considered and, furthermore, the creep resistance of only three of these steels was known.

In order to obtain further information with respect to the relative merits of the short-time rupture test, it was believed advisable to subject to this test certain of the steels used in the study of manufacturing variables. Since certain information was available with respect to the creep characteristics of these steels, it could thus be determined whether or not the steels would be arranged in the same relative order on the basis of the two tests. The results obtained are contained in the present report.

TABLE I.—CHEMICAL COMPOSITION OF STEELS USED IN ACCEPTABILITY TESTS.

Steel Designation	Chemical Composition, per cent						Aluminum Addition, per cent	Process	McQuaid-Ehn Grain Size
	C	Mn	P	S	Si	V			
52	0.46	0.54	0.016	0.030	0.23	....	0.105	Basic Open Hearth	5 to 7
56	0.51	0.75	0.018	0.033	0.21	....	0.10	Basic Open Hearth	5 to 7
393	0.37	0.70	....	....	0.16	0.18	....	....	8
K20	0.35	0.55	0.016	0.030	0.19	....	0.06	Basic Open Hearth	7 to 8

STEELS INVESTIGATED

The steels used in this investigation were obtained from Battelle Memorial Institute in the form of 1-in. bars. Information with respect to their chemical composition, melting practice, melting process, and McQuaid-Ehn grain size are given in Table I. With one excep-

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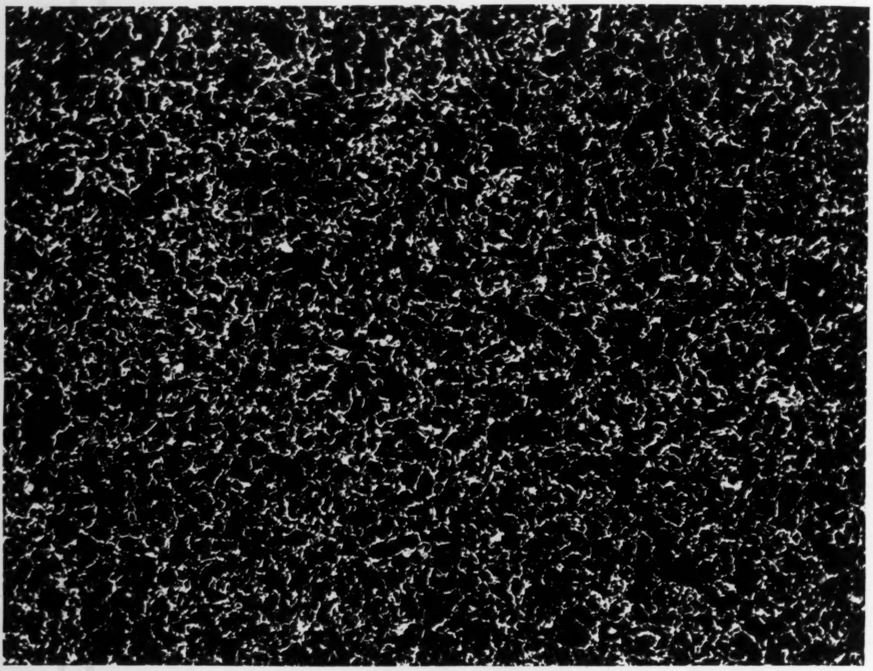
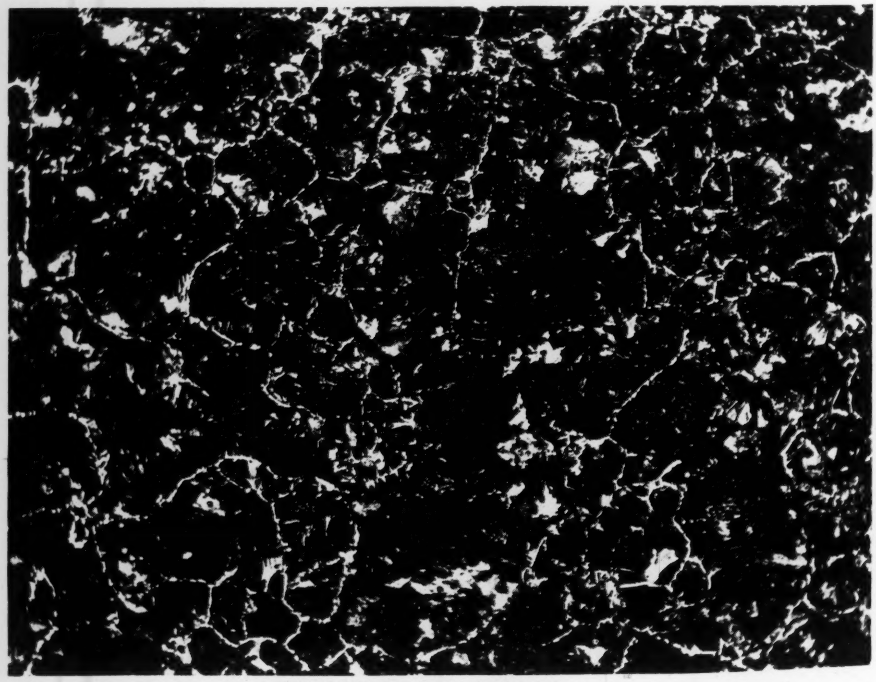
[1] Howard C. Cross and J. G. Lowther, "Progress Report on Study of Effects of Manufacturing Variables on the Creep Resistance of Steels," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 149 (1938).

[2] A. E. White and C. L. Clark, "Report on Acceptability Tests for High-Temperature Characteristics," *Ibid.*, p. 142.

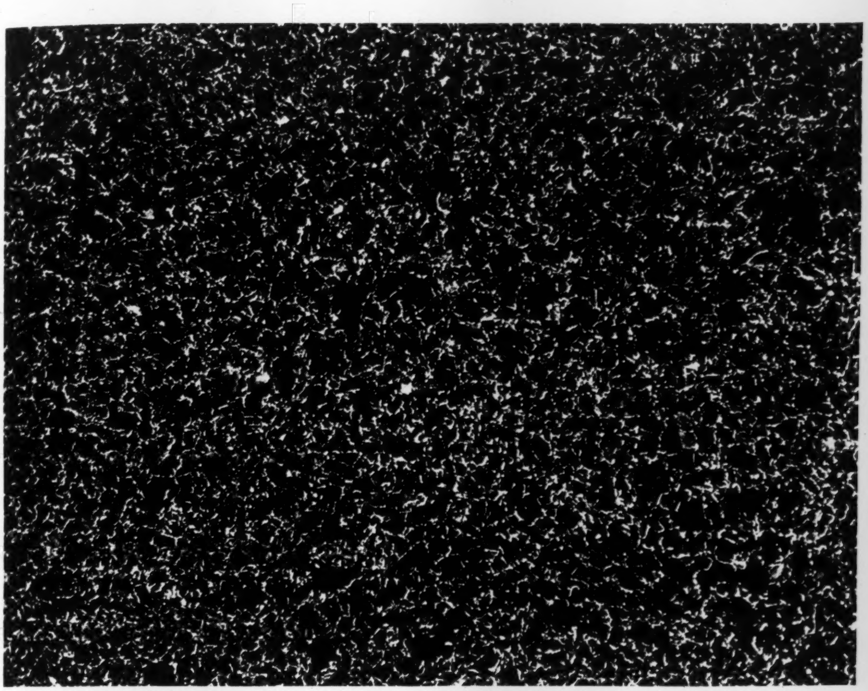


(a) 1550 F., 45 min. (grain size 6 to 8).

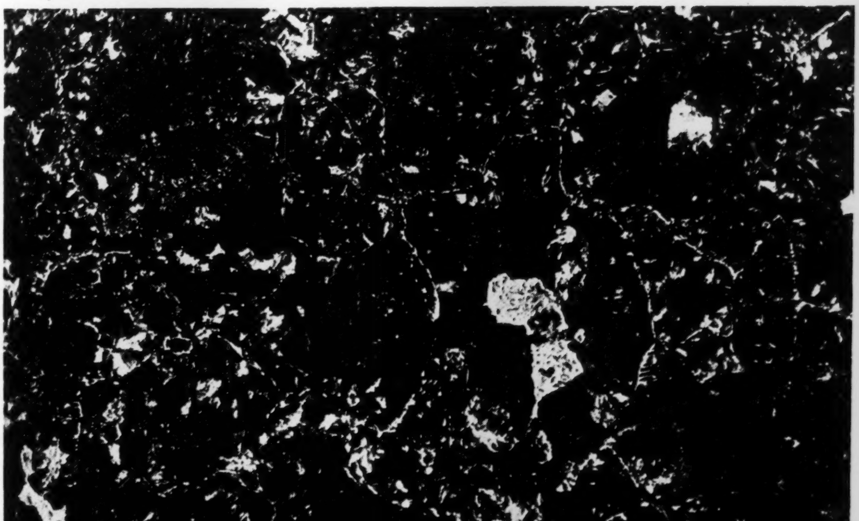


(b) 1800 F., 45 min. (grain size 2 to 4).

FIG. 1.—Austenitic Grain Size of Steel 54 (0.46 per cent Carbon).

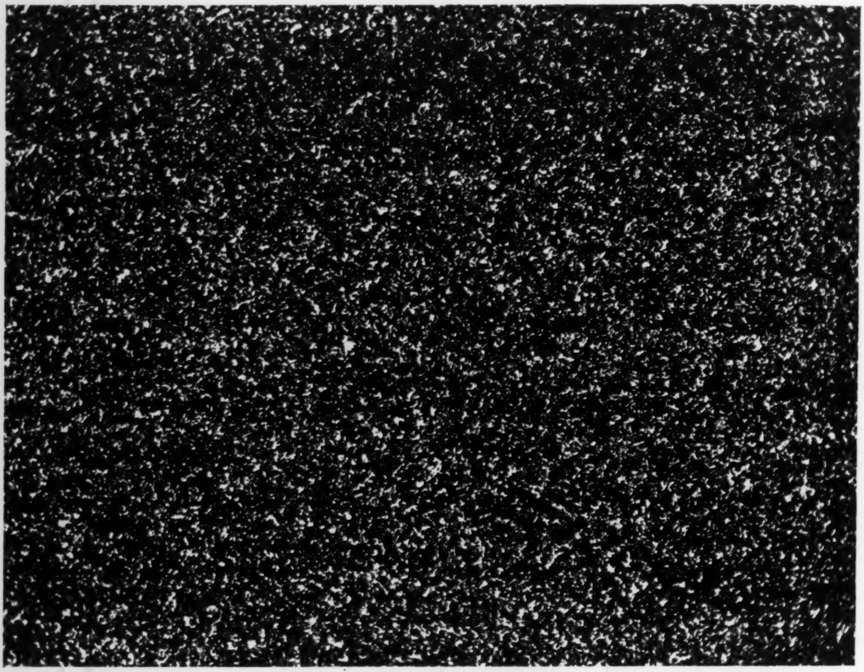


(*a*) 1550 F., 45 min. (grain size 6 to 8).

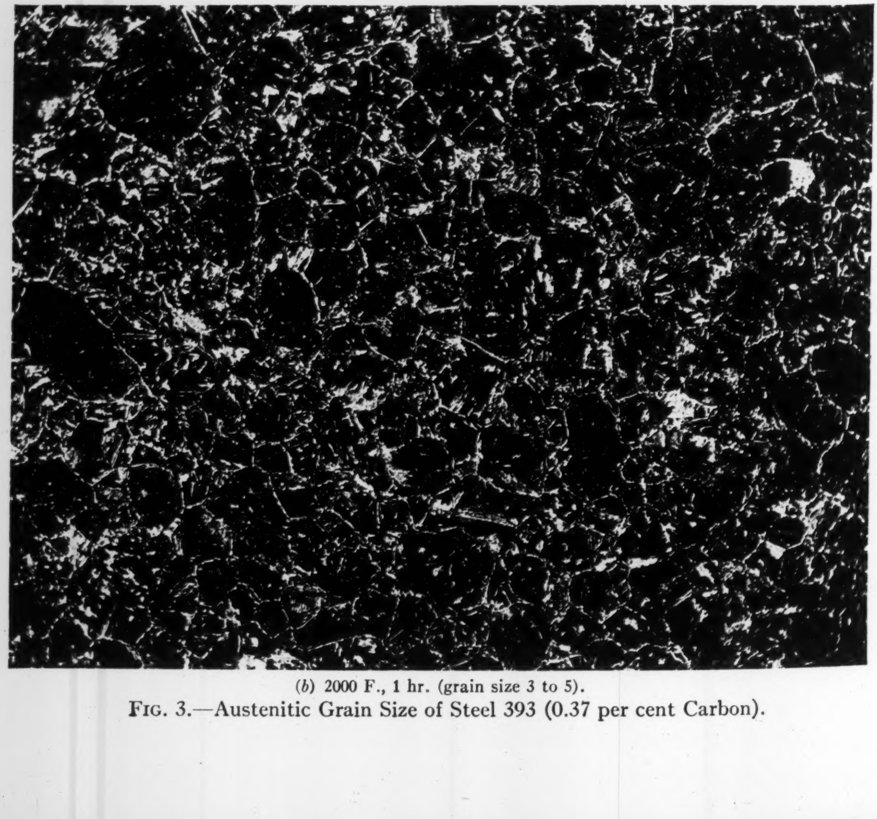


(*b*) 1850 F., 45 min. (grain size 2 to 4).

FIG. 2.—Austenitic Grain Size of Steel 56 (0.51 per cent Carbon).

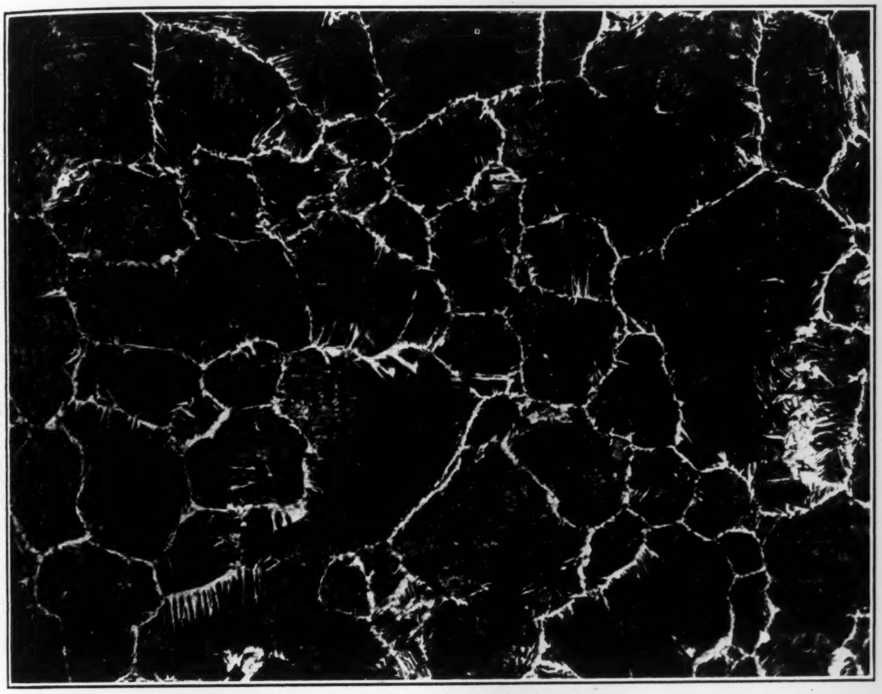


(*a*) 1600 F., 1 hr. (grain size 8).



(*b*) 2000 F., 1 hr. (grain size 3 to 5).

FIG. 3.—Austenitic Grain Size of Steel 393 (0.37 per cent Carbon).



1900 F., 2 hr.; 1900 F., 6 hr. (grain size 1 to 3).

FIG. 4.—Austenitic Grain Size of K20 Steel (0.35 per cent Carbon).

tion, the steels are of the plain carbon type, containing 0.35 to 0.51 per cent carbon. Steel 393 likewise contains 0.18 per cent vanadium.

The steels were given the same heat treatments as employed by Battelle and special care was taken to have all the details in strict accordance with those previously used in order that the resulting grain sizes would be the same. A portion of each steel was heat treated to produce a fine austenitic grain and this treatment consisted of air cooling from either 1550 or 1600 F. The remaining portion of each steel was heat treated to produce a coarse austenitic grain. The temperatures for this purpose varied from 1800 to 2000 F.

The microstructures of Figs. 1 to 4 show the austenitic grain size for each of the steels in both conditions of heat treatment and these same results are summarized in Table II.

If the results of Table II be compared with those previously reported by Battelle, very good agreement will be found to exist. Slight differences are found in steel 393 in that the grain size variations in the coarsened steel was previously found to range from 2 to 5, and in the case of K20 steel, the previous range was from 0 to 3.

TABLE II.—AUSTENITIC GRAIN SIZE WHEN SUBJECTED TO DESIGNATED TREATMENTS.

Steel Designation	Heat Treatment	Austenitic Grain Size
52-1	1550 F., 45 min.	6 to 8
52-2	1800 F., 45 min.	2 to 4
56-1	1550 F., 45 min.	6 to 8
56-2	1850 F., 45 min.	2 to 4
393-1	1600 F., 1 hr.	8
393-2	2000 F., 1 hr.	3 to 5
K20 (1)	1550 F., 45 min.	8
K20 (2)	1900 F., 2 hr. and 6 hr.	1 to 3

PROCEDURE

Description of the apparatus and procedure employed in the short-time stress-rupture tests were given in the earlier report.[2] As previously stated, the test is relatively simple in that it consists of fracturing a series of specimens at each temperature under fixed loads so chosen that the resulting fracture times vary from a few minutes up to a maximum of 15 hr. The stresses and corresponding fracture times, when plotted to logarithmic coordinates, form an approximately straight-line relationship at each of the temperatures. It is thus possible to determine the stress corresponding to a definite fracture time, such as 10 hr.

TABLE III.—STRESS-RUPTURE DATA.

Steel Designation	Temperature, deg. Fahr.	Stress, psi.	Time, hr.	Elongation in 2 in., per cent	Reduction of Area, per cent
STEEL 52					
52-1[a]	950	50 250	S.T.T.S.[h]	43.0	81.5
	950	45 000	0.083	41.5	80.3
	950	40 000	0.60	43.0	77.2
	950	36 500	1.40	42.0	76.6
	950	29 000	10.0	43.0	74.5
	850	63 000	S.T.T.S.	40.5	79.9
	850	58 000	0.083	40.5	78.4
	850	49 000	2.88	40.5	76.4
	850	45 000	6.41	39.5	76.3
52-2[b]	950	51 500	S.T.T.S.	35.0	72.3
	950	41 000	0.63	37.5	68.6
	950	35 000	4.5	35.0	69.0
	950	32 000	11.7	35.0	69.5
	850	67 500	S.T.T.S.	33.0	68.4
	850	58 000	0.50	32.0	61.8
	850	50 000	4.27	30.0	55.5
	850	47 000	14.2	28.5	56.5
STEEL 56					
56-1[a]	950	55 000	S.T.T.S.	40.0	80.9
	950	46 000	0.38	42.0	77.8
	950	41 000	1.45	41.0	74.5
	950	38 000	2.55	40.0	72.3
	950	33 000	12.52	38.5	68.2
	850	69 250	S.T.T.S.	36.0	79.8
	850	60 000	0.37	37.0	78.8
	850	55 000	1.70	40.0	77.0
	850	50 000	9.17	38.0	73.3
56-2[c]	950	62 000	S.T.T.S.	32.0	72.9
	950	52 000	0.32	28.5	64.0
	950	44 000	4.13	26.5	56.0
	950	40 000	10.67	27.0	56.5
	850	77 000	S.T.T.S.	27.0	65.2
	850	68 000	0.37	25.0	54.7
	850	65 000	1.56	21.0	47.2
	850	62 000	5.03	20.0	42.5
	850	60 000	4.32	20.5	43.7
	850	58 000	16.5	19.5	41.6
STEEL 393					
393-1[d]	850	68 125	S.T.T.S.	35.0	73.5
	850	63 000	0.133	36.5	74.9
	850	58 000	4.52	37.0	73.5
	850	56 500	8.12	39.5	74.9
393-2[e]	850	90 000	S.T.T.S.	19.0	43.4
	850	83 000	0.28	17.0	30.2
	850	79 000	1.48	12.0	19.9
	850	76 000	2.45	11.0	17.7
	850	70 000	11.77	7.5	11.5
STEEL K20					
K20 (1)[f]	850	45 000	S.T.T.S.	52.5	79.5
	850	40 000	0.40	56.0	79.5
	850	36 000	1.67	56.0	79.5
	850	32 500	8.30	57.5	79.2
	850	31 000	13.92	53.0	78.4
	750	55 500	S.T.T.S.	49.0	76.8
	750	51 000	0.48	49.5	74.5
	750	49 000	1.22	52.5	75.6
	750	45 000	6.33	52.5	75.3
	750	43 000	10.33	55.5	78.9
	750	42 000	21.60	55.5	76.6
K20 (2)[g]	850	62 750	S.T.T.S.	27.0	56.0
	850	55 000	0.90	22.0	38.8
	850	53 000	1.80	20.0	34.7
	850	50 000	5.68	15.5	30.2
	750	76 400	S.T.T.S.	29.5	58.8
	750	69 000	0.95	26.0	49.8
	750	67 000	2.19	24.5	48.9
	750	65 000	7.32	20.5	40.4

[a] 1550 F., 45 min., air cooled (6 to 8—Austenitic grain size).

[b] 1800 F., 45 min., air cooled (2 to 4—Austenitic grain size).

[c] 1850 F., 45 min., air cooled (2 to 4—Austenitic grain size).

[d] 1600 F., 1 hr., air cooled (8—Austenitic grain size).

[e] 2000 F., 1 hr., air cooled (3 to 5—Austenitic grain size).

[f] 1550 F., air cooled (8—Austenitic grain size).

[g] 1900 F., 2 hr., air cooled; 1900 F., 6 hr., air cooled (1 to 3—Austenitic grain size).

[h] S.T.T.S. = Short-time tensile strength.

In the present investigation, specimens of each of the four steels were given both of the heat treatments listed in Table II. In each case the specimens heat treated at the lower temperature possessed a fine austenitic grain size, and those heat treated at the higher temperature possessed a coarse austenitic grain size. The results obtained will, therefore, indicate the influence of austenitic grain size on the rupture strength.

TEST RESULTS

The results obtained from stress-rupture tests of a maximum of 15 hr. duration on these four steels are shown graphically in Figs. 5 to 8, inclusive, and likewise given in Tables III to V.

The four figures, which are plotted to logarithmic coordinates, clearly show the coarse-grained austenitic steels to possess the greater rupture strength at each of the temperatures considered. The difference in strength between the coarse and fine austenitic grained steels appears to be relatively constant for steels 52, 56, and 393 and of a greater order of magnitude for steel K20.

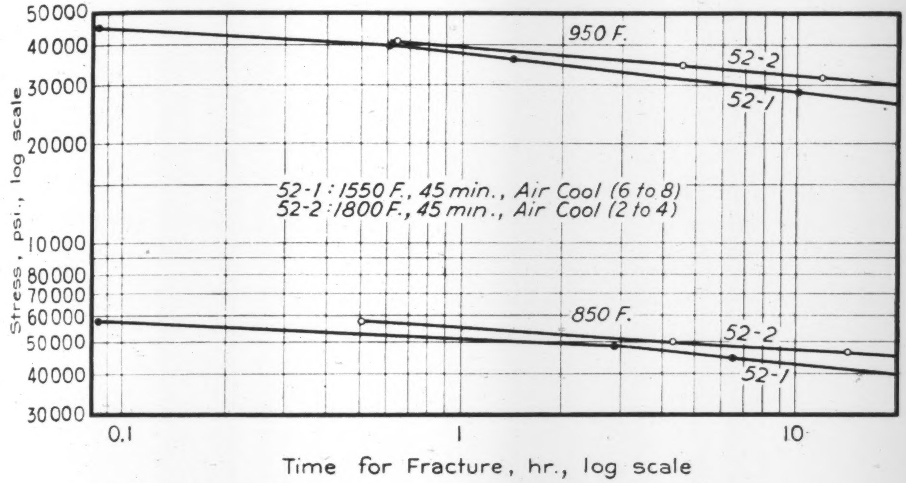


FIG. 5.—Stress-Rupture Characteristics at 850 and 950 F. of Steel 52.

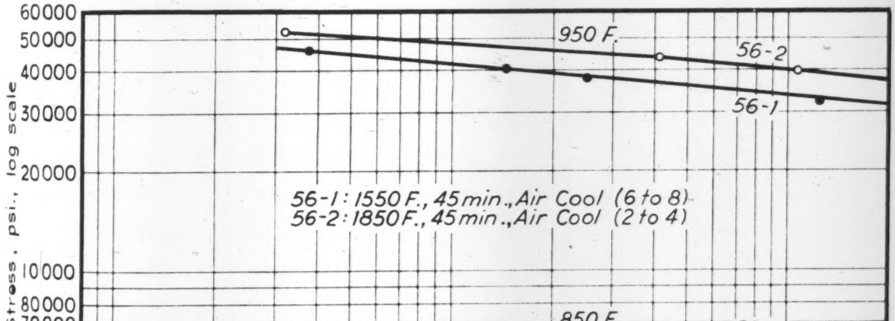


FIG. 6.—Stress-Rupture Characteristics at 850 and 950 F. of Steel 56.

Table III contains, in addition to the stresses and corresponding fracture times, information with respect to the ductility of the fractured specimens. Even though the testing time periods in these tests are relatively short, the ductility values do give an indication of the influence of time and stress on both the elongation and reduction of area. With all four steels considered, the ductility of the coarse austenitic grain steels is less than that of the corresponding fine-grained materials. In the case of steel 52, the difference is not of a large order of magnitude. With the remaining three coarse-grained steels, the ductility decreases as the stress decreases, and the time for fracture increases, and the question arises as to how low the available ductility would fall as the stress would be further decreased, that is, in passing from the rupture tests to the creep tests.

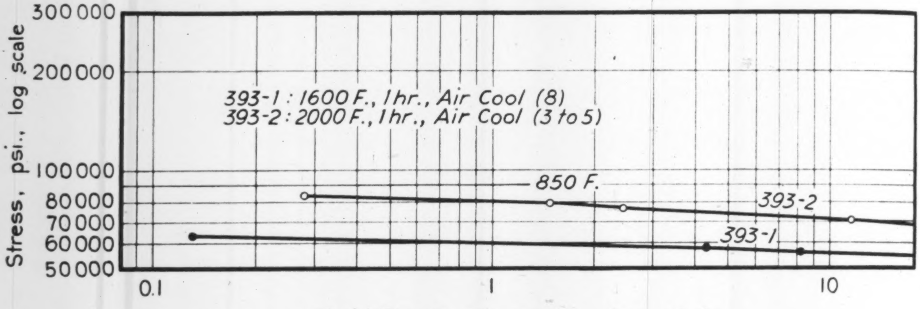


FIG. 7.—Stress-Rupture Characteristics at 850 F. of Steel 393.

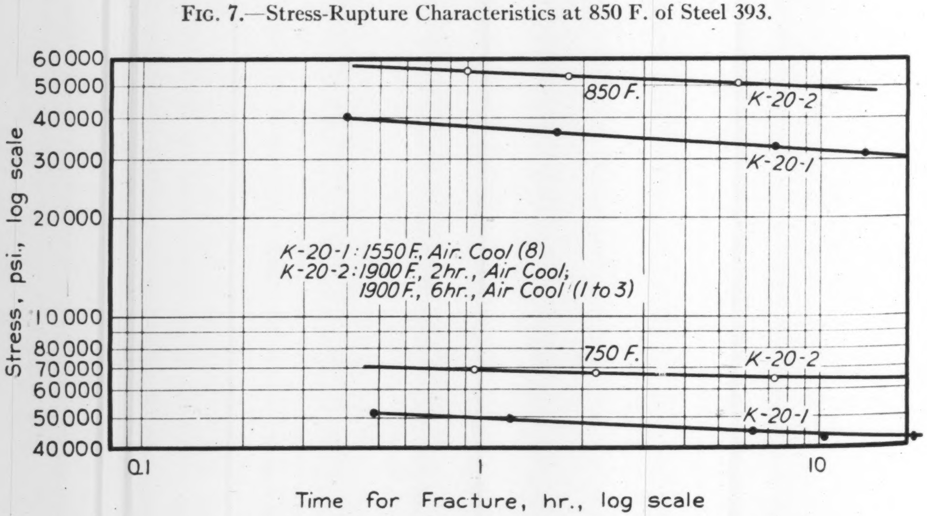


FIG. 8.—Stress-Rupture Characteristics at 750 and 850 F. of Steel K20.

Table IV summarizes the results from the stress-rupture tests, while Table V shows the comparative influence of austenitic grain size on the short-time rupture strength. In this table, the comparison in the stress-rupture strength is made on the ratio of the stresses required for fracture in 10 hr.

In the case of the rupture strength, the range in the ratio is only from 0.65 to 0.90. Furthermore, this observed range in the ratio is directly proportional to the difference between the extremes of the austenitic grain size considered.

For example, in steels 52 and 56 the fine austenitic grain size had a rating of 6 to 8 and the coarse a rating of 2 to 4. For both of these steels the range in the ratio was only from 0.84 to 0.90. For steel K20, the fine austenitic grain size had a rating of 8 and the coarse a rating of 1 to 3 and the average ratio was lower, being approximately 0.67. In other words, as should be expected, the superiority of the coarse grain structure over the fine grain steel increases as the relative spread between the grain sizes considered increases.

TABLE IV.—SHORT-TIME STRESS-RUPTURE CHARACTERISTICS OF DESIGNATED STEELS.

Steel Designation	Austenitic Grain Size	Temperature deg. Fahr.	Stress for Fracture in 10 hr., psi.
52-1[a]........	6 to 8	950	29 000
		850	43 000
52-2[b]........	2 to 4	950	32 500
		850	48 000
56-1[c]........	6 to 8	950	34 000
		850	49 500
56-2[d]........	2 to 4	950	40 000
		850	59 000
393-1[e]	8	850	56 000
393-2[f]........	3 to 5	850	70 000
K20 (1)[g]	8	850	31 800
		750	43 800
K20 (2)[h]	1 to 3	850	48 800
		750	64 000

[a] 1550 F., 45 min., air cooled.
[b] 1800 F., 45 min., air cooled.
[c] 1550 F., 45 min., air cooled.
[d] 1850 F., 45 min., air cooled.
[e] 1600 F., 1 hr., air cooled.
[f] 2000 F., 1 hr., air cooled.
[g] 1500 F., air cooled.
[h] 1900 F., 2 hr., air cooled; 1900F., 6 hr., air cooled.

DISCUSSION OF RESULTS

On the basis of these results, it is to be concluded that both the 500-hr. creep tests and the 15-hr. stress-rupture tests show the coarse-grained austenitic steels to possess the superior high-temperature strength at the temperatures considered. The stress-rupture test shows the influence of the grain size effect to be relatively constant in all four steels and at each of the temperatures considered. This test likewise yields information with respect to the influence of grain size on the high-temperature ductility and shows the fine-grained steels to possess the greater ductility, especially under the longer fracture time periods.

TABLE V.—COMPARATIVE INFLUENCE OF AUSTENITIC GRAIN SIZE ON THE SHORT-TIME STRESS-RUPTURE CHARACTERISTICS.

Steel	Temperature deg. Fahr.	Ratio of Fine Grained to Coarse Grained Fracture Stresses[a]
52...........	950	0.89
	850	0.90
56...........	950	0.85
	850	0.84
393..........	850	0.80
K20........	850	0.65
	750	0.68

[a] Comparison based on stress required for fracture in 10 hr.

APPENDIX III

CORRELATION OF TEST RESULTS FOR VARIOUS TYPES OF HIGH-TEMPERATURE TESTS CARRIED OUT FOR THE JOINT RESEARCH COMMITTEE

PREPARED BY E. A. DAVIS

Under the sponsorship of the A.S.M.E.-A.S.T.M. Joint Research Committee on Effect of Temperature on the Properties of Metals, several different tests have been made on a carbon molybdenum steel at 800 and 1050 F. Everett and Clark[1] have made torsion and tension creep tests at the University of Michigan while F. H. Norton[2] has made tension creep and internal pressure tests at the Massachusetts Institute of Technology.

These tests may all be classified as creep tests since they were carried out under conditions of constant load. It was felt that these tests should be compared from some common point of view, and the correlation of the test results has been assigned to the present author.

BASIS FOR COMPARISON

In comparing different types of tests, it is quite advantageous to express the results of all the tests by means of some common set of variables. The success of such an attempt at correlation will depend largely upon a proper selection of the variables to be used. A general state of stress is defined by three principal stresses, σ_1, σ_2, and σ_3, and their directions which are mutually perpendicular. The most generally accepted criteria for correlation would be to compare the octahedral shearing stress with the shearing strain rate in the planes in which this stress acts. This octahedral shearing stress τ_n, is given by the expression:

$$\tau_n = \tfrac{1}{3}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{\frac{1}{2}}$$

In two papers Nadai[3,4] has developed the means for comparing the several types of tests used in this investigation. Expressions have been developed which give the octahedral stress and strain for the common types of loading.

COMPARISON OF TESTS

From the first of Nadai's papers[3] referred to, we get the transformation equations by which torsion and tension tests can be compared. These equations for small strains are:

$$\gamma_n = \sqrt{2}\,\epsilon \quad \text{. . . . . (1)}$$

$$\tau_n = \frac{\sqrt{2}}{3}\,\sigma \quad \text{. . . . . (2)}$$

$$\gamma_n = \frac{\sqrt{2}}{\sqrt{3}}\,\gamma \quad \text{. . . . . (3)}$$

$$\tau_n = \frac{\sqrt{2}}{\sqrt{3}}\,\tau \quad \text{. . . . . (4)}$$

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[1] F. L. Everett and C. L. Clark, "Torsion Creep Tests for Comparison with Tension Creep Tests on a Carbon-Molybdenum Steel," see p. 215.

[2] F. H. Norton, "Creep in Tubular Pressure Vessels," *Transactions*, Am. Soc. Mechanical Engrs., April, 1939.

[3] A. Nadai, "Plastic Behavior of Metals in the Strain Hardening Range, Part I," *Journal of Applied Physics*, Vol. 8, No. 3, March, 1937.

[4] A. Nadai, "On the Creep of Solids at Elevated Temperature," *Journal of Applied Physics*, Vol. 8, No. 6, June, 1937.

TABLE I.—DATA FROM TESTS BY EVERETT AND CLARK.

T, Temp., deg. Fahr.	σ, psi.	τ, psi.	$\frac{d\epsilon}{dt}$, per cent per 1000 hr. at 1000 hr.	$\frac{d\gamma}{dt}$, per cent per 1000 hr. at 1000 hr.	τ_n, psi.	$\frac{d\gamma_n}{dt}$, per cent per 1000 hr. at 1000 hr.
800	....	16 000	....	0.041	13 080	0.033
	....	14 000	....	0.023	11 450	0.019
	....	12 000	....	0.0143	9 820	0.0117
	....	11 000	....	0.0033	9 000	0.0027
	30 000	....	0.112	....	14 150	0.158
	25 000	....	0.034	....	11 800	0.048
	22 000	....	0.018	....	10 750	0.025
1050	....	9 000	....	0.69	7 360	0.564
	....	7 500	....	0.051	6 140	0.0416
	....	5 670	....	0.035	4 640	0.0286
	....	4 500	....	0.006	3 680	0.0049
	12 000	....	0.082	....	5 660	0.1060
	10 000	....	0.047	....	4 720	0.0665
	8 000	....	0.022	....	3 770	0.031
	7 000	....	0.015	....	3 300	0.021

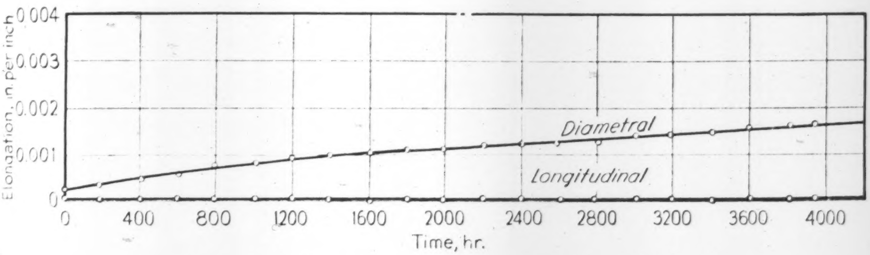

FIG. 1.—Tubular Creep Tests by F. H. Norton, 1050 F., 1617 psi. Pressure.

where:

γ_n = shear strain on octahedral plane,
τ_n = shear stress on octahedral plane,
ϵ = unit elongation in tension test,
σ = axial stress in tension test,
γ = shear strain in torsion test, and
τ = shear stress in torsion test.

The strain rates are obtained by differentiating Eqs. 1 and 3.

$$\frac{d\gamma_n}{dt} = \sqrt{2}\,\frac{d\epsilon}{dt} = \frac{\sqrt{2}}{\sqrt{3}}\,\frac{d\gamma}{dt} \ldots . (5)$$

By using these equations, the values of τ_n and $\frac{d\,\gamma_n}{dt}$ can be obtained for the results given in Fig. 5 of the report by Messrs. Everett and Clark. These data are shown in Table I.

The case of the cylinder with closed ends under internal pressure is more complicated, but it has been treated in the second of Nadai's papers.[4] The case has been worked out for the "steady state of creep" condition when the octahedral shear stress τ_n is related to the corresponding shear rate, $\frac{d\,\gamma_n}{dt}$, by the power function expression

$$\tau_n = \tau_1 \left(\frac{v}{v_1}\right)^m$$

where $v = \frac{d\,\gamma_n}{dt}$ and τ_1, v_1 and m are constants. The constant m will be the slope of the stress-strain rate curve on the double log plot as has been used by the investigators (Fig. 5, Everett and Clark and Fig. 11, Norton) and is quite close to 0.25.

Nadai[4] has shown that for a tube with closed ends the longitudinal strain should be zero. Norton's curves, one of which is reproduced in Fig. 1, shows this effect very nicely.

In the elastic state the tangential stress is higher at the inner radius than at the outside while in the plastic state when a steady state of creep occurs and m has a value of 0.25 the tangential stress is greatest at the outside radius. The octahedral shear stress, τ_n, does not change greatly with the radius for the tube dimensions used in these tests. In this case, at the inside radius

$$\tau_n = 2.04\,p \ldots\ldots\ldots . (6)$$

where p is the internal pressure. At the outside radius

$$\tau_n = 1.84\,p \ldots\ldots\ldots\ldots (7)$$

TABLE II.—DATA FROM TESTS BY NORTON.

T, Temp., deg. Fahr.	σ, psi.	p, psi.	$\frac{d\epsilon}{dt}$, per cent per 1000 hr.	$\frac{d\epsilon_t}{dt}$, per cent per 1000 hr.	τ_n, psi.	$\frac{d\gamma_n}{dt}$, per cent per 1000 hr.
800....	17 230	....	0.003	....	8 120	0.00425
	39 170	....	0.22	....	18 500	0.31
	....	4 000	....	0.007	7 760	0.014
1050...	6 970	....	0.048	....	3 290	0.068
	13 930	....	....	....	6 570	2.76
	....	1 620	....	0.058 to 0.022	3 150	0.116 to 0.044
	....	3 230	....	1.39	6 260	2.76

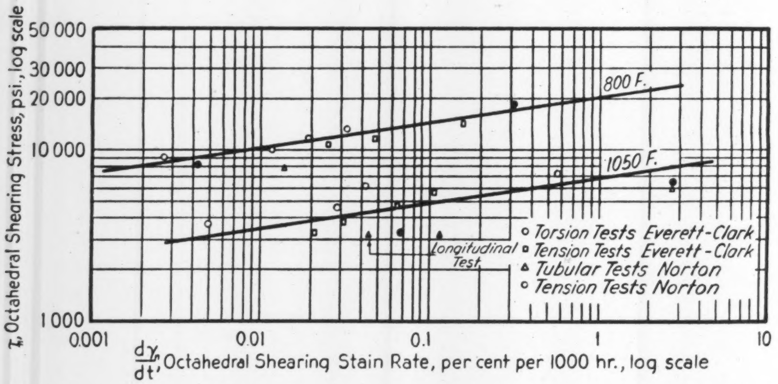

FIG. 2.—Comparison of Various Types of Creep Tests on a Carbon-Molybdenum Steel.

The mean value of 1.94 p was taken as the value of stress to be used for comparison purposes.

The strains also are nonuniform throughout the material, but vary with the radius of the tube. If we focus our attention on the strain at the mean radius it may be well to point out that the increase in the outside diameter is the result of two opposing factors. Since the longitudinal strain is zero, the radial strain must be just the negative of the tangential strain. An increase in tangential strain tends to increase the diameter while the radial strain reduces the thickness of the tube and this tends to decrease the diameter. This has been taken into account in determining the rate of shear in the octahedral planes.

By making use of the Nadai transformation equations, it was found that the octahedral shear rate at the mean radius was approximately 1.99 times the tangential strain rate plotted by Norton. The converted data on the tests made at the Massachusetts Institute of Technology are given in Table II.

The results of all the tests are shown in Fig. 2. The agreement at 800 F. is fair while at 1050 F. there is considerable scattering. This scattering, however, is not all due to the difference in the type of test used. There is quite a difference between the tensile creep tests carried on at the University of Michigan and those made at the Massachusetts Institute of Technology. These variations may be due to differences in the material or any of the factors which ordinarily cause differences in creep test results.

With particular reference to the scattering observed in Fig. 2, it should be pointed out that the material used by Norton for both tensile and internal pressure tests may have been of smaller grain size than that used by Everett & Clark. This, at least, is indicated by the micrographs included in Appendix VI of the Report of the Joint Research Committee for 1938.[5] However, this alone does not explain all the scattering, unless the effect due to grain size changes greatly with temperature, for the tensile creep tests on the two materials agree well at 850 F. while the small grain material shows more rapid rates at 1050 F.

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[5] Report Covering Information on Steels for Tubular Creep Tests and Other Test Work of the Joint Committee, prepared by H. J. Kerr, J. B. Romer, and H. D. Newell, *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 172 (1938).

REPORT OF COMMITTEE B-1

ON

COPPER AND COPPER-ALLOY WIRES FOR ELECTRICAL CONDUCTORS

Committee B-1 on Copper and Copper Alloy Wires for Electrical Conductors held two meetings during the year: one in Atlantic City, N. J., on June 29, 1938, and one in New York City on April 26, 1939.

The committee records with sorrow the death of H. C. Jennison, representative of the American Brass Co. on the committee. The committee sent flowers to the funeral and a telegram of condolence to Mr. Jennison's sister, Miss Helen C. Jennison.

Changes in membership of the committee during the year consist of the following:

J. R. Freeman, Jr., replaces H. C. Jennison as a representative of the American Brass Co.,

R. S. Pratt replaces W. R. Webster, as representative of the Bridgeport Brass Co.,

C. T. Sinclair of the Duquesne Light Co. replaces C. D. Gray as representative of the American Institute of Electrical Engineers, and

The Phelps Dodge Refining Corp. has taken over the membership of the Nichols Copper Co., C. S. Harloff continuing as the representative on this committee.

Committee B-1 now consists of 15 producer, 13 consumer, and 2 general interest members, making a total of 30, represented on the committee by 34 individuals.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I (G. E. Dean, chairman) has made its final report on the subject of transmission cable specifications, the recommendations being incorporated in proposed revisions of Specifications B 8, reported below. The work of this subcommittee having been completed, it was discharged by action of the committee at the April meeting.

Subcommittee II (P. H. Grogan, chairman) reports progress, confirming for the time being recommendations on speed of testing made last year,[1] and reporting that the subcommittee is continuing studies in collaboration with Committee E-1 on Methods of Testing.

Subcommittee III (T. S. Fuller, chairman) reports progress in the study of the packaging section of the Specifications for Soft or Annealed Copper Wire (B 3), and recommends that the packaging section be changed to the status of a note. The work of the subcommittee is to continue, collaborating with committees of the National Electrical Manufacturers Association working on standard packages for wire.

Subcommittee IV (J. R. Becker, chairman) has recommended a number of pertinent revisions in the present Standard Specifications for Soft Rectangular Copper Wire (B 48), after finding that the present specifications are not acceptable in some respects to many consumers and a number of producers. The proposed revision in the form of new tentative specifications recognizes two classes of rectangular wire, one class being suitable for all applications except possibly those involving extreme edgewise bending, and the other class being particularly applicable for edgewise bending purposes. A bending test is incorporated in the proposed specifications for this latter class of material, in place of the tension test prescribed for the other class of material. Elongation values for the tension test prescribed are increased, and certain modifications are made in the permissible variations of dimensions in order to bring these requirements more nearly in line with present practice in the industry. Many revisions of an editorial nature are also incorporated in the revised specifications which will be submitted to the Society subsequent to the annual meeting through Committee E-10 on Standards.[2]

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 182 to 184 (1938).

Subcommittee V (P. H. Grogan, chairman) has recommended revisions in the Specifications for Copper Rods for Wire Drawing (B 49), which are incorporated in the proposed revision of this standard referred to below.

Subcommittee VI (W. R. Hibbard, chairman) has presented a revision of the Specifications for Bare Stranded Copper Cable (B 8) with respect to the length of lay. The recommendations of the subcommittee were accepted and the subcommittee discharged.

Subcommittee VII (R. S. Pratt, chairman) reported on the speed of testing of trolley wire, confirming its former recommendations[1] and stating that further investigations of this problem are in process.

Subcommittee VIII (W. H. Bassett, Jr., chairman) has been working on proposed specifications for rope lay cable in cooperation with a similar group of the Insulated Power Cable Engineers Association, and hopes to be able to present a draft of proposed tentative specifications sometime next year.

Subcommittee IX (G. E. Dean, chairman) completed its work in drafting an acceptable inspection clause, and has been discharged.

Subcommittee X (chairman not yet appointed) has been designated by Committee B-1 to study and report on the use of lead or lead-alloy coverings for the protection of copper wire, looking toward the preparation of standard specifications for this product.

Subcommittee XI (R. S. Pratt, chairman) has been formed to study the problems of high-conductivity special alloy copper wires.

Subcommittee XII (C. S. Gordon, chairman) has been appointed to investigate and prepare specifications on tin-coated, hard-drawn, medium-hard drawn, and alloy wires for electrical conductors. It is reported that there is some demand for such specifications to supplement the Specifications for Copper Wire for Rubber Insulation (B 33), which cover soft drawn or annealed copper wires, tin-coated so as to be suitable for use with rubber insulation.

Subcommittee XIII (W. H. Bassett, Jr., chairman) has been formed to study proper bend testing equipment and methods of test for copper and copper-alloy wire. This subcommittee will collaborate with Committee B-4 on Electrical-Heating, Resistance, and Furnace Alloys which has developed the Tentative Method for Bend Testing of Wire (for Radio Tubes and Incandescent Lamps) (B 113 - 38 T).

I. NEW TENTATIVE STANDARD

Tentative Specifications for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage:[3]

There has been an insistent demand for standard specifications covering figure-9 deep-section grooved and figure-8 trolley wire which is largely used for industrial haulage purposes. The engineering department of the National Electrical Manufacturers' Association has been in communication with the committee, and a special committee of the American Mining Congress has voted favorably on the standardization of figure-9 deep-section, grooved trolley wire. The committee considered the suggestions that an A.S.T.M. standard be prepared covering this product, and it is the committee's opinion that these shapes should not be added to the present trolley wire standard (B 47), but that separate specifications should be prepared covering this particular class of material. Accordingly, the committee has prepared new specifications for this material which it is presenting to the Society for publication as tentative.[3]

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[2] See Editorial Note, p. 242.

[3] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

II. REVISIONS OF STANDARDS

The committee recommends for immediate adoption revisions in seven standard specifications as explained below, and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society. Except as specifically noted below, these revisions consist of editorial changes in wording and arrangement, together with the addition of desirable explanatory notes, tables, etc., to make the specifications more generally useful without changing the intent materially.

Standard Specifications for Hard-Drawn Copper Wire (B 1 – 38),[4] and for Medium Hard-Drawn Copper Wire (B 2 – 38):[4]

A slight modification has been made in the paragraph which provided that wire with diameters lying between listed sizes meet the requirements prescribed for the next larger size, to allow a permissible variation of three mils in diameter as to the application of such requirements for listed sizes if the diameter is 0.100 in. or over, and a permissible variation of two mils in diameter if the listed size is less than 0.100 in. Also, the values in Table I have been extended to four significant figures, rather than three, and for wire having nominal diameters of less than 0.100 in., provision has been made for expressing diameter in decimals to four places. However, the permissible variations from the nominal diameter are retained without change. The specifications in their revised form are appended hereto.[5]

Standard Specifications for Soft or Annealed Copper Wire (B 3 – 38):[4]

Table I has been revised, giving to four significant figures information as to diameter, area, tensile strength, elongation, etc. It is felt that this table will be of use to the industry and no change has been made in the prescribed tensile strength or elongation. A slight revision in the requirement for tensile properties has been made in that wire whose nominal diameter exceeds by one mil the size listed in Table I, but which is less than that of the next larger size, shall conform to the requirements prescribed for the next larger size. For wire having nominal diameters less than 0.100 in., it is proposed that the size may be expressed in decimals not to exceed four places, although the permissible variations from the nominal diameters remain as heretofore. The specifications in their revised form are appended hereto.[5]

Standard Specifications for Tinned Soft or Annealed Copper Wire for Rubber Insulation (B 33 – 38):[4]

These specifications have been extensively rearranged, and have been revised by the incorporation of the revisions proposed above for Specifications B 3. No other changes involving intent are being made, but it is felt that the rearrangement and amplification of the specifications[5] with the associated notes will be of value to the industry.

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[4] 1936 Book of A.S.T.M. Standards, Part I, pp. 655 to 673.

[5] These specifications were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

Standard Specifications for Hot-Rolled Copper Rods for Wire Drawing (B 49 – 26):[6]

In addition to the editorial changes described above to make the specifications of the committee uniform, the committee is accepting the following revisions in substance, recommended by Subcommittee V, which it is felt very definitely improve these specifications and make them more acceptable to industry:

The title is being changed to make it more descriptive of the actual use of the rods; the number of samples required for tension tests has been increased from 2 to 4 per 50,000 lb. of rod produced; the method for determining resistivity values, not formerly specified, is now definitely prescribed; a rod having a nominal diameter of 0.250 in. is now given a permissible variation of plus or minus 0.010 in. to conform with similar tolerances for rods of the next larger prescribed diameter; and provision is definitely made for either black or cleaned rods, as designated by the purchaser. The specifications, as revised, are appended hereto.[5]

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Spec. for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage	19	0	7
II. REVISIONS OF STANDARDS			
Spec. for Hard-Drawn Copper Wire (B 1 – 38), immediate adoption	25	0	1
Spec. for Medium Hard-Drawn Copper Wire (B 2 – 38), immediate adoption	25	0	1
Spec. for Soft or Annealed Copper Wire (B 3 – 38), immediate adoption	25	0	1
Spec. for Tinned Soft or Annealed Copper Wire for Rubber Insulation (B 33 – 38), immediate adoption	25	0	1
Spec. for Hot-Rolled Copper Rods for Wire Drawing (B 49 – 26), immediate adoption	22	0	4
Spec. for Bronze Trolley Wire (B 9 – 38; A.S.A. H 22.1 – 1938), immediate adoption	23	0	3
Spec. for Copper Trolley Wire (B 47 – 38; A.S.A. H 22.2 – 1938), immediate adoption	23	0	3
III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for Hard-Drawn Copper Alloy Wires for Electrical Conductors (B 105 – 38 T), as revised	19	0	5
Spec. for Bare Stranded Copper Cable, Hard, Medium-Hard or Soft (B 8 – 38 T), as revised	22	0	3
IV. WITHDRAWAL OF STANDARD			
Spec. for Bare, Stranded Copper Cable, Hard, Medium-Hard, or Soft (B 8 – 36)	22	0	3

Standard Specifications for Bronze Trolley Wire (B 9 – 38; A.S.A. H 22.1 – 1938),[7] *and for Copper Trolley Wire (B 47 – 38; A.S.A. H 22.2 – 1938)*:[7]

Editorial changes only are proposed in these two specifications which are presented herewith in their revised form.[5]

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[6] 1936 Book of A.S.T.M. Standards, Part I, p. 642.

[7] 1937 Supplement to Book of A.S.T.M. Standards, pp. 32, 38.

III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

Tentative Specifications for Hard-Drawn Copper Alloy Wires for Electrical Conductors (B 105 – 38 T):[8]

These specifications were issued in 1936, and revised in 1937 and 1938, in accordance with the dictates of experience. A number of editorial changes have now been made in the specifications without affecting, to any material extent, their intent. The editorial modifications consist of changes in wording and arrangement together with the addition of explanatory notes to make the specifications uniform, in so far as practicable, with other specifications under the jurisdiction of the committee. The committee recommends that these specifications be approved for reference to letter ballot of the Society for adoption as standard.

Tentative Specifications for Bare, Stranded Copper Cable, Hard, Medium-Hard, or Soft (B 8 – 38 T):[8]

The committee has accepted the recommendations of Subcommittees I and VI with respect to these specifications and is presenting certain revisions in Section 4 on Lay, and in Section 9 on Packing and Shipping together with certain editorial changes to make the specifications uniform with other specifications under the jurisdiction of the committee. It is recommended that these specifications, as revised,[5] be approved for reference to letter ballot of the Society for adoption as standard, replacing the present Standard Specifications B 8 – 36, which are recommended to be withdrawn.

IV. WITHDRAWAL OF STANDARD

Standard Specifications for Bare, Stranded Copper Cable, Hard, Medium-Hard, or Soft (B 8 – 36):[9]

Since the committee is recommending the revision and adoption as standard of Tentative Specifications B 8 – 38 T, it is recommended that the present standard specifications be withdrawn.

The above recommendations have been submitted to letter ballot of the committee which consists of 30 members; 00 members returned their ballots, with the results shown in Table I.

This report has been submitted to letter ballot of the committee which consists of 30 members; 26 members returned their ballots, of whom 23 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. H. FOOTE,
Chairman.

G. E. DEAN,
Secretary.

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[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 672, 677 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 338, 343.

[9] 1936 Book of A.S.T.M. Standards, Part I, p. 638.

EDITORIAL NOTE

Subsequent to the annual meeting Committee B-1 presented to the Society through Committee E-10 on Standards proposed Tentative Specifications for Soft Rectangular and Square Copper Wire for Electrical Conductors to replace immediately the Standard Specifications for Soft Rectangular Copper Wire (B 48 – 38). This recommendation was accepted by Committee E-10 on August 24, 1939, and the new tentative specifications appear in the 1939 Book of A.S.T.M. Standards, Part I, bearing the designation B 48 – 39 T.

REPORT OF COMMITTEE B-2

ON

NON-FERROUS METALS AND ALLOYS

Committee B-2 on Non-Ferrous Metals and Alloys held one meeting during the year: on June 30, 1938, in Atlantic City, N. J., during the annual meeting of the Society. Several of the subcommittees have also held meetings during the year.

R. F. Mehl, who served as chairman of the committee since 1935, resigned the chairmanship in December, 1938, finding that his duties were becoming more and more centered in the iron and steel field and that it was difficult to allot time to the work of the committee. The Advisory Committee, at its meeting in New York City on February 15, 1939, accepted the resignation with reluctance, and the secretary was instructed to record in the minutes of the meeting the gratitude of the members of Committee B-2 to Dr. Mehl for his services during his incumbency. The Advisory Committee, acting as a nominating committee, in accordance with the By-laws, nominated the present secretary, E. E. Thum, as chairman, and Carl E. Swartz as secretary, the election to be held at the June meeting of the committee.

Subsequent to the 1938 annual meeting, Committee B-2 presented to the Society through Committee E-10 on Standards the following recommendations:

Tentative Specifications for Electrolytic Cathode Copper (B 115 - 38 T).

Reversion to tentative and revision of Standard Specifications for:
Phosphor Tin (B 51 - 27),
Phosphor Copper (B 52 - 27),
Silicon Copper (B 53 - 27), and
Brazing Solder (B 64 - 28).

These recommendations were accepted[1] by Committee E-10 on August 25, 1938, and appear in the 1938 *Proceedings*.[2]

Adoption of Tentative Standard as Standard

The committee recommends that the Tentative Specifications for Rolled Zinc (B 69 – 37 T)[3] be adopted as standard to replace the present Standard Specifications B 69 – 29.[4] This recommendation has been submitted to letter ballot of the committee which consists of 97 members; 72 members returned their ballots, of whom 40 have voted affirmatively, 0 negatively, and 32 marked their ballots "not voting."

Subcommittee II on Refined Lead, Tin, Antimony, and Bismuth (T. A. Wright, chairman) is planning to hold a meeting prior to the June meeting of Committee B-2. At the request of the Insulated Power Cable Engineers' Association the subcommittee has been giving consideration to the preparation of specifications for copper-bearing lead (cable sheathing). During the year attention has been called by the Lead Industries Association to the desirability of having A.S.T.M. specifications for calking lead, and a request has been received from the Eagle-Picher Sales Co. that a specification for pig lead be adopted similar to that for the grade of soft Missouri lead designated as common lead (Grade IIIb) in the former Specifications for Pig Lead (B 29 - 23).

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[1] In submitting these recommendations to Committee E-10 on Standards, Committee B-2 reported the following results of the letter ballot vote of a total of 79 ballots returned from a committee membership of 95: B 115 – 38 T, affirmative 49, negative 0, ballots marked "not voting" 21, ballots unmarked 9; B 51 – 38 T, affirmative 44, negative 0, ballots marked "not voting" 26, ballots unmarked 9; B 52 – 38 T, affirmative 49, negative 0, ballots marked "not voting" 22, ballots unmarked 8; B 53 – 38 T, affirmative 48, negative 0, ballots marked "not voting" 23, ballots unmarked 8; B 64 - 38 T, affirmative 49, negative 0, ballots marked "not voting" 23, ballots unmarked 7.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 683, 709, 711, 713, 707 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 349, 414, 416, 418, 404.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 698 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 406.

[4] 1936 Book of A.S.T.M. Standards, Part I, p. 705.

Subcommittee III on White Metal Alloys (G. H. Clamer, chairman) held a meeting in Columbus, Ohio, on March 8, 1939, and approved the revision of the Standard Specifications for Solder Metal (B 32 - 21; A.S.A. H 11-1924) and the reversion of the specifications to the tentative status. After approval by Committee B-2, this recommendation is to be submitted to the Society through Committee E-10 on Standards.

Subcommittee IV on Refined Zinc and Wrought Zinc (E. H. Bunce, chairman) has made several unavailing efforts, through a group headed by J. R. Townsend, to cooperate with the zinc rolling industry and devise acceptance tests for rolled zinc, as proposed when the Tentative Specifications for Rolled Zinc (B 69-37 T) were last revised. Since such cooperative action seems impossible to secure, it was decided that the project should be abandoned, and with the consent of the Advisory Committee the subgroup was discharged, with appreciation for its services.

This report has been submitted to letter ballot of the committee which consists of 101 members; 79 members returned their ballots, of whom 75 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

E. E. THUM,
Secretary.

EDITORIAL NOTE

Subsequent to the annual meeting Committee B-2 presented to the Society through Committee E-10 on Standards proposed Tentative Specifications for Nickel-Copper Alloy Plate, Sheet, and Strip. These new tentative specifications were accepted by Committee E-10 on August 24, 1939, and appear in the 1939 Book of A.S.T.M. Standards, Part I, bearing the designation B 127 - 39 T.

REPORT OF COMMITTEE B-3
ON
CORROSION OF NON-FERROUS METALS AND ALLOYS

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys held two meetings during the year: one in Atlantic City, N. J., on June 29, 1938, and one in Columbus, Ohio, on March 7, 1939.

The committee has been active during the past year through its subcommittees I on Total Immersion Test, III on Spray Test, VI on Atmospheric Corrosion, and VIII on Galvanic and Electrolytic Corrosion in carrying forward the programs under the sponsorship of these subcommittees.

Subcommittee II on Alternate Immersion Test has been inactive during the past year.

At the meeting in Atlantic City, a special committee was appointed for the purpose of revising the committee's by-laws. A proposed revision of the by-laws was approved for reference to letter ballot of Committee B-3 at the meeting in Columbus.

A new Subcommittee IV on Specifications (E. A. Anderson, Chairman) was appointed at the Columbus meeting for the purpose of preparing specifications for electroplated coatings on non-ferrous alloys.

NEW TENTATIVE STANDARD

The committee recommends a proposed Method of Salt Spray Testing of Non-Ferrous Metals for publication as tentative.[1] This recommendation has been submitted to letter ballot of the committee which consists of 59 members; 47 members returned their ballots, of whom 44 voted affirmatively, 0 negatively, and 3 members marked their ballots "not voting."

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Total Immersion Test (J. R. Freeman, Jr., chairman).—This subcommittee has formulated plans for testing the reproducibility of results in the total immersion test, using three solutions and testing six metals in each solution. The solutions and metals to be tested are as follows:

NORMAL SODIUM CHLORIDE BRINE

Material	Designation
Commercial copper, phosphorized	B
Commercial aluminum	G
Commercial nickel	T
Chemical lead	U
Commercial zinc (Prime Western grade)	AA
Commercial tin	EE

NORMAL SULFURIC ACID

Material	Designation
Commercial copper, phosphorized	B
Commercial aluminum	G
Commercial nickel	T
Chemical lead	U
Red brass (85 cu, 15 zn)	L
Brass (70 cu, 30 zn)	M

NORMAL SODIUM HYDROXIDE

Material	Designation
Commercial copper, phosphorized	B
Commercial nickel	T
Chemical lead	U
Commercial zinc (High grade)	BB
Commercial tin	EE
Brass (70 cu, 30 zn)	M

Tests will be made in aerated and non-aerated solutions at 35 C. by at least four cooperating laboratories, and it is expected that the tests will actually be started early in the summer of 1939.

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[1] This method was accepted as tentative by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part I.

Subcommittee III on Spray Test (E. H. Dix, Jr., chairman).—Subcommittee III has prepared a proposed Method of Salt Spray Testing of Non-Ferrous Metals which is recommended for publication as tentative,[1] as mentioned earlier in this report. This subcommittee is undertaking a study of methods of calibrating salt spray fog densities and a study of salt spray testing in large chambers.

Subcommittee VI on Atmospheric Corrosion (W. H. Finkeldey, chairman).—In the early part of 1938, Subcommittee VI prepared a report[2] summarizing the changes in tensile properties, loss in weight determinations, and visual inspection of the 24 non-ferrous metals and alloys exposed to the atmosphere for approximately six years at nine test sites. Some comment on the results was included in the report but no conclusions were drawn since, in the opinion of the subcommittee, the tests have not progressed far enough to permit this to be done. The report is the third that has been made on the materials exposed to the atmosphere, the two previous inspection reports[3] having been made after exposures of one and three years. The 1938 report includes, also, a brief summary of the previous results.

In response to a general demand from the subcommittee members for some critical discussion of the results so far obtained in these tests, it was decided to encourage the presentation of a paper on this subject. Prof. C. W. Borgmann of the University of Colorado, Boulder, Colo., has agreed to undertake this assignment. The paper entitled "Atmospheric Corrosion of Non-Ferrous Metals and Alloys"[4] is being presented at this annual meeting of the Society.

The methods of statistical analysis applied to the results of the tension tests have been the subject of some criticism since these methods were first used several years ago. A subgroup has been appointed to review the methods now in use and to submit to Subcommittee VI recommendations either for improvement of the present methods or abandonment entirely if the investigation shows that statistical analysis methods are of little value in this particular case. The exposure tests in the atmosphere are being continued, and the next removal of specimens has been tentatively set for 1944.

A paper, sponsored by this committee, on "Chemical Removal of Corrosion Products in the Determination of the Corrosion Rate of Zinc" by E. A. Anderson and C. E. Reinhard of the New Jersey Zinc Co., appears as an Appendix to this report.[5]

Subcommittee VIII on Galvanic and Electrolytic Corrosion (L. J. Gorman, chairman).— This subcommittee has continued its test program and a report containing data obtained from these tests has been prepared, as appended hereto, covering results of atmospheric corrosion tests on galvanic couples over a 7-yr. period.

This report has been submitted to letter ballot of the committee which consists of 59 members; 47 members returned their ballots, of whom 44 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

T. S. FULLER,
Chairman.

SAM TOUR,
Secretary.

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[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 194 (1938).

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part I, p. 234 (1933); Vol. 35, Part I, p. 142 (1935).

[4] See p. 674.

[5] See p. 691.

REPORT OF SUBCOMMITTEE VIII ON GALVANIC AND ELECTROLYTIC CORROSION

This report presents the results of a series of tests, started in 1931, to determine the corrosion behavior of nonferrous metals when exposed to typical atmospheres in couple combination with other metals. Two previous reports covering test periods of 1 and 3 yr. were rendered in 1934[1] and 1935,[2] respectively. This report is a record of the data on the corrosion which has occurred over a period of approximately seven years and includes a summary of the results obtained in the two previous periods. Since this is the final report on these tests, an effort has been made to draw such conclusions as are justified from the scope and nature of the tests. At the outset, the tests were designed to measure only corrosion due to couple action. It became evident, as the test progressed, that several unforeseen factors were operating to complicate the situation. In considering the test data presented in this report, these variables which are considered in detail under the discussion, later in the report, should be given careful attention because the results are occasionally distorted by their operation.

Test Locations:

The locations and classification of the nine test sites, at which the tests were made, are given in Table I. These test sites are also used by Subcommittee VI of Committee B-3 and other A.S.T.M. committees for atmospheric tests. Three general types of atmosphere are represented, namely, seacoast, industrial, and rural. Complete information regarding the meteorological conditions at the test locations is given in the 1932 report of Committee B-3.[3] The climatic conditions are also described by Subcommittee VI in the 1938 report of Committee B-3.[4] A detailed discussion of these conditions has been omitted from this report because no direct correlation has been found between the corrosion behavior of the metals and meteorological data. The available data on climatic conditions do not take into account the many factors which affect the corrosiveness of the atmosphere, such as, the degree of industrial contamination, the frequency and duration of wetting and drying the specimens, the effect of fog, dew fall and frost formation. Factors of this sort are probably of greater importance

TABLE I.—TEST LOCATIONS.

Location	Atmosphere Classification
LaJolla (San Diego), Calif.	Southwestern seacoast
Sandy Hook, N. J.	Northeastern seacoast
Key West, Fla.	Southeastern seacoast
Pittsburgh, Pa.	Industrial
Altoona, Pa.	Industrial
Rochester, N. Y.	Industrial (humid)
New York, N. Y.	Industrial (seacoast)
State College, Pa.	Rural
Phoenix, Ariz.	Rural (dry)

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part I, p. 236 (1934).

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 167 (1935).

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part I, p. 214 (1932).

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 194 (1938)

than the climatic conditions as described by temperature, precipitation, relative humidity, sunshine, etc. Furthermore, the general classification of atmospheres as given in Table I cannot be taken too literally. For example, there is considerable difference between the corrosiveness of the atmosphere at Pittsburgh, Altoona, New York, and Rochester, all of which are classified as "industrial."

The following paragraphs summarize the general conditions at each of the test locations. It should be borne in mind, that, although the test locations are in general typical of the surrounding area, the intensity of any corrosive attack varies with specific local conditions:

La Jolla, Calif.—The test site is located on the seacoast of southern California. The test rack is approximately 100 ft. from, and 25 ft. above the water line. The rack is subject to considerable spray and to the unusually heavy fog and dew falls which are characteristic of this particular region on the Pacific coast.

Sandy Hook, N. J.—The test rack is located at Fort Hancock, near the extreme tip of the Hook projecting into the bay, within approximately 100 yd. of the water line. The rack at this location does not seem to be subject to much spray. There is some industrial contamination from the shops and buildings of Fort Hancock. The rainfall and other climatic conditions are about the same as New York City.

Key West, Fla.—This location, in the United States Government Naval Station, is within a short distance of the water's edge. The atmosphere is typical of seacoast conditions along the south Atlantic coast line. The climate is milder than at Sandy Hook, the average temperature higher and the rainfall heavier; otherwise, conditions are approximately the same. The appearance of the rack does not indicate that it is subject to much spray.

Pittsburgh, Pa.—The test rack is located on Brunot's Island in the Ohio River, approximately three miles from Pittsburgh. The atmosphere is representative of large manufacturing communities and is contaminated by smoke and industrial gases from factories and steel mills on both banks of the river, as well as by the stack gases from the large power generating station located on the island. The Pittsburgh area is subject to heavy fogs, particularly during the late fall and winter. The humidity throughout the year is relatively high and particularly so at the test location, which is located only a few feet above the river at the water's edge. The test couples at this location were immersed under water for several days in March, 1936, during flood conditions on the Ohio River.

Altoona, Pa.—The test rack is located on the roof of a storehouse in the yard of the Pennsylvania Railroad. The atmosphere at this location is perhaps more heavily contaminated than at Pittsburgh because of its close proximity to the railroad yards and forge shops, both of which are sources of large quantities of smoke and gas from the combustion of soft coal. The climatic conditions are substantially the same as Pittsburgh.

Rochester, N. Y.—The test rack is located in the gorge of the Genesee River, a short distance below the falls. The humidity at this particular point is very high because of the spray and mist from the falls. The atmosphere is also contaminated by gases from an illuminating gas plant and various other factories located in the gorge in close proximity to the test rack.

New York, N. Y.—The test rack, located on the roof of the Bell Telephone Laboratories building at 463 West St., is directly opposite the steamship docks in the Hudson River. The atmosphere is contaminated by smoke and gases from the steamships and other vessels operating in the river and from numerous industrial plants in the vicinity.

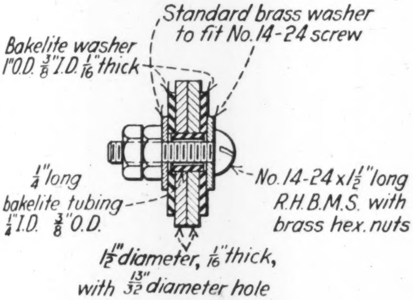
Standard brass washer to fit No. 14-24 screw
Bakelite washer 1" O.D. $\frac{3}{8}$" I.D. $\frac{1}{16}$" thick
$\frac{1}{4}$" long bakelite tubing $\frac{1}{4}$" I.D. $\frac{3}{8}$" O.D.
No. 14-24 x $1\frac{1}{2}$" long R.H.B.M.S. with brass hex. nuts
$1\frac{1}{2}$" diameter, $\frac{1}{16}$" thick, with $\frac{13}{32}$" diameter hole

FIG. 1.—Test Specimen.

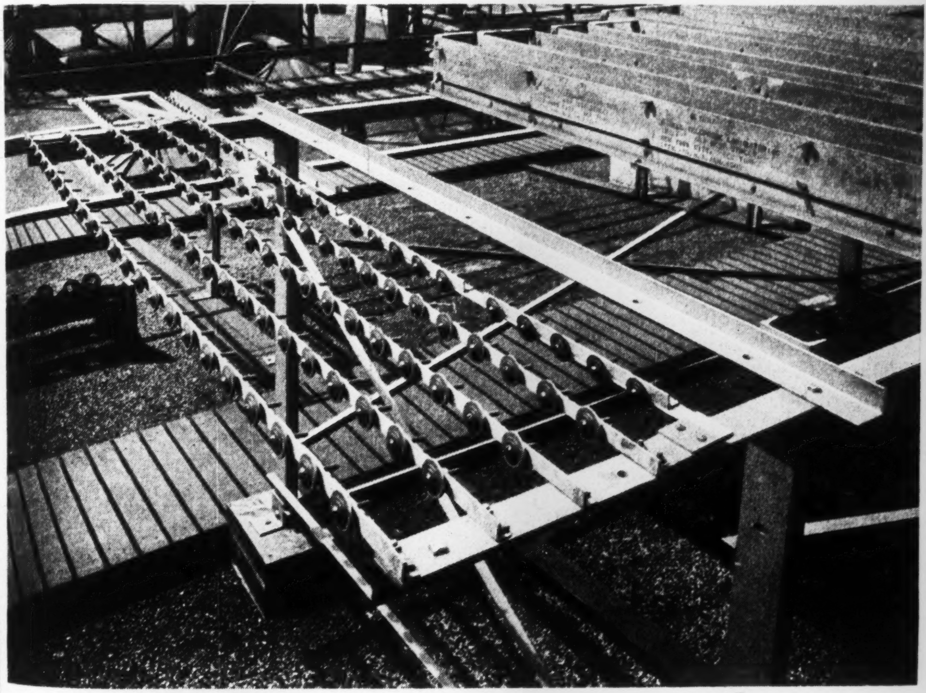

FIG. 2.—Typical Test Rack.

State College, Pa.—The test location is on the experimental farms of the Pennsylvania State College. With the exception of one farm house, there are no nearby habitations. The climatic conditions are generally representative of the humidity and precipitation conditions in the inland rural areas of eastern United States. The atmosphere is unusually free from contamination by industrial gases because there are no large industries within ten miles of the test site.

Phoenix, Ariz.—The test rack is located on the properties of the Phoenix Light and Power Co. on the outskirts of the City. The location, although classified as "rural" is unlike most other rural districts in the United States. The climate is hot and dry with very little rainfall and is fairly representative of the dry and semi-arid sections of the southwestern part of the country.

Test Couples:

The tests included all couple combinations of the metals given in Table II. The metallurgical history of these metals is given in the 1932 report of Committee B-3.[3] The type of test specimen and the manner of coupling is illustrated in Fig. 1. In addition to the various couple combinations, two disks of each metal were coupled together and tested as blanks in order to determine the normal corrosion of the metals when assembled in the form of the test couples. Figure 2 shows a typical test rack and illustrates the manner in which the couples were mounted. The outer faces of the metal disks were protected by paint in order to confine the corrosion to the edges and the metal to metal surfaces of the couples. The paint did not afford protection in all cases and the results obtained on many couples were influenced by corrosion of the outer surfaces.

TABLE II.—TEST METALS.

Identification Letter	Metal	
G	Aluminum	(99.1+ per cent)
A	Copper	(99.9 per cent)
GG	Iron	(Mild steel)
U	Lead	(99.9+ per cent)
T	Nickel	(99.3 per cent)
EE	Tin	(99.8+ per cent)
BB	Zinc	(99.0+ per cent)

Originally four complete sets of couples were exposed at each of the test locations. The first set was removed in 1932 and the second set in 1934, as stated above. The third and fourth sets were removed and shipped to New York City during July and August of 1938. The periods of exposure at each test location are given in detail in Table III. The following is a report on the third set of couples, which were exposed for a period of approximately seven years. The couples in the fourth set were inspected and used, where necessary, to check apparent discrepancies in the data obtained from the third set.

Contact Resistance and Visual Inspection:

When the test bars, with the couples in place, were returned to New York City, the contact resistance between the metal disks was measured and the couples were inspected at a meeting of the subcommittee. The inspection was first made with the couples in place on the test bars to determine the amount and color of the edge corrosion products, the spreading of the edges of the disks and the effectiveness of the paint protection on the outer surfaces of the disks.

TABLE III.—EXPOSURE PERIODS AT TEST LOCATIONS.

Location	Date of Exposure, Sets A, B, C, D, 1931	Periods of Exposure, yr.		
		First Period, Set A	Second Period, Set B	Third Period, Sets C and D
LaJolla, Calif.	Sept. 1	1.0	3.0	7.0
Sandy Hook, N. J.	April 14	1.0	3.0	7.5
Key West, Fla.	Oct. 12	1.0	3.1	7.0
Pittsburgh, Pa.	July 8	1.0	3.0	7.0
Altoona, Pa.	June 1	1.0	3.0	7.1
Rochester, N. Y.	Sept. 21	1.0	3.0	7.0
New York, N. Y.	March 23	1.0	3.0	7.4
State College, Pa.	Sept. 4	1.0	3.0	7.1
Phoenix, Ariz.	June 8	1.0	3.0	7.1

After this inspection, which was made on both sets of bars, the couples on the third set were disassembled and the inner surfaces inspected to determine the amount and color of the corrosion products and the distribution of the corrosion. The results of the resistance measurements and the visual inspection are given in Table IV (Plate II). It should be noted that the resistance measurements were made in the laboratory after the corrosion film had been given a chance to dry out. Since moisture almost invariably lowers resistance to a marked extent, the values given in Table IV are probably in general much higher than those prevailing during the test.

Legend

Contact Resistance
- Inf. - Over 250,000 ohms
- 00 - Less than 0.5 ohm
- M - Following a number indicates thousands; for example 5 M is 5000.
- X - Resistance not measured

Amount of Corrosion Products
- T - Tarnish
- S - Small
- M - Medium
- H - Heavy
- VH - Very Heavy

Distribution of Corrosion
- Ge - General
- Sp - Spotty
- Ed - Edge

Color of Corrosion Products
- Gr - Gray
- Gn - Green
- Bk - Black
- Br - Brown
- Bl - Blue
- W - White

Couple	La Jolla, Calif.						Sandy Hook, N.J.						Keywest,		
	Contact Res. Ohms	Edge Spread	Edge Cor.Prod. Amt.Color	Paint Protection %	Face Cor. Prod. Amt.Dist.Color	Face Cor. Prod. % Not Cor.	Contact Res. Ohms	Edge Spread	Edge Cor.Prod Amt.Color	Paint Protection %	Face Cor. Prod. Amt.Dist.Color	Face Cor. Prod. % Not Cor.	Contact Res. Ohms	Edge Spread	Edge Cor.Prod. Amt.Color
Al	5 M	Slight	M Gr	80	H Ge Gr	0	Inf.	Slight	S Br	100	M Ge Gr-Br	0	Inf.	Tight	S Rd-W
Al			M Gr	80	H Ge Cr	0			S Br	100	M Ge Gr-Br	0			S Rd-W
Al	7 M	Wide	M Gr	95	VH Ge Gn-Gr	0	Inf.	Medium	S Br	100	H Ge Gr-Gn	0	Inf.	Slight	S Br-W
Cu			S Gn	0	H Ge Br-Gr	0			S Gr	80	H Ge Gr-Gn	0			S Br-W
Al	Inf.	Wide	M Br-W	85	H Ge L.Br	0	Inf.	Wide	S Bk	100	H Ge Br	0	80M	Tight	M W-Br
Fe		Badly	Corroded		H Ge D.Br	0			H Br	95	H Ge Br	0			M Br
Al	78M	Wide	M Gr-W	60	H Ge Gr	0	215	Wide	S Br	100	H Ge Gr-Br	0	6.0	Medium	S Br-W
Pb			S Gr-W	20	H Ge D.Gr*	0			S Bk-Gr	100	H Ge Gr-Br	0			S W
Al	12M	Medium	M Br-W	90	VH Ge Gr-Gn-Br	0	120M	Medium	S Br	100	M Ge Gn-Br	0	1.0	Tight	S Gr
Ni			M Br-W	0	S Sp Gr	10			S Br	100	M Ge Gr-Br	5			S Gr
Al	800	Wide	M W-Gr	80	H Ge Gr	0	23M	Wide	S Br	100	M Ge Gr-Br	0	0.0	Medium	Rd-W
Sn			M W-Gr	0	VH Ge Gr*	0			S Br-W	95	M Ge Gr-Br	0			S Rd-W
Al	00	Tight	H W	70	S Sp Gr	10	1.0	Tight	S Br	100	S Sp Gr	15	15M	Tight	S Gr
Zn			H W	0	S Sp Gr	15			S Br-W	5	S Sp Gr	20			S W-Gr
Cu	33M	Tight	S Gr	60	M Ge Rd-Gr	0	0.0	Tight	S Br-Gn	100	T - -	100	1.0	Tight	S Br
Cu			S Gr	60	M Ge Rd-Gr	0			S Br-Gn	100	T - -	100			S Br
Cu	Inf.	Tight	S Br	15	M Ge Br	0	Inf.	Wide	S Bk	95	H Ge Br	0	0.0	Wide	S Br
Fe			VH Br	0	Disintegrated	0			H Br-Bk	95	VH Ge Br	0			H Br
Cu	1.0	Tight	S Gn-W	10	S Ge Bl-Rd	10	0.0	Slight	S Br	100	T - -	100	0.0	Tight	S Br
Pb			M W	90	S Ge Bl-Gr	10			S Br-W	100	S Sp Br	90			S Br-Rd
Cu	00	Slight	M Gn	50	M Ge Bl-Rd	0	0.0	Tight	S Br-Gn	100	T - -	100	0.0	Tight	S Gr
Ni			S Gr-Gn	80	M Ge Bl-Rd	0			S Br	100	T - -	100			S Br
Cu	00	Tight	S Gn-W	0	S Ge Gr-Rd	0	0.0	Slight	S Br	100	S Ge Gr	10	3.0	Slight	S Br
Sn			M W	60	S Ge Gr-Gn	0			S W-Gn	100	S Ge Gr	10			S W
Cu	2.0	Tight	M G-W	0	M Ge Gr-Bl	0	0.0	Tight	S Bk	100	S Ge Rd Gn	5	Inf.	Tight	S Gr
Zn			H Gr	0	M Ge Gr-Bl	0			S Bk-W	10	S Ge Gr	5			S W
Fe	X	Badly	Corroded	and	Disintegrated		Inf.	Wide	H Br-Bk	90	VH Ge Rd-Br	0	Inf.	Medium	M Br
Fe		Badly	Corroded	and	Disintegrated				H Br-Bk	90	VH Ge Rd-Br	0			M Br
Fe	X	Wide	Badly Corroded		VH Ge Br	0	Inf.	Wide	H Br-Bk	95	H Ge Br	0	23M	Slight	S Br
Pb			S Br	100	VH Ge Br*	0			L Br-Bk	100	H Ge Br*	0			S Br-Gr
Fe	X	Missing					Inf.	Wide	H Br	80	H Ge Br	0	Inf.	Tight	S Br-Bk
Ni		Missing							S Br-Gr	100	H Ge Br	0			S Br
Fe	X	Wide	Badly Corroded		VH Ge Br	0	8.0	Wide	H Br	60	VH Ge Br	10	2.0	Wide	M Br-Bk
Sn			M Br-W	95	VH Ge Br*	0			S Br	100	VH Ge Br*	10			S Br-W
Fe	X	Tight	M Br-W	0	H Ge Bl-Br	5	Inf.	Tight	S Br	15	S Ge Br	0.	2.0	Tight	M Gr
Zn			Vh W	0	H Ge Gr-Br*	0			S Br-Gr	0	S Ge Gr-Br	0			M Gr
Pb	00	Slight	VS Gr	100	S Ge Gr	20	0.0	Tight	S Br-Gr	100	S Ge Gr	0	0.0	Slight	S Rd-W
Pb			VS Gr	100	S Ge Gr	20			S Br-Gr	100	S Ge Gr	0			S Rd-W
Pb	00	Slight	S Gr-Br	95	S Ge Gr-Br	5	0.0	Tight	S Gr	100	S Sp Gr-Br	40	0.0	Tight	S W
Ni			S Gr-Br	95	S Ge Gr	10			S Br	100	S Sp Gr	40			S Gr
Pb	00	Slight	H Gr-W	0	S Ge Gr	15	2 M	Slight	S Gr	100	S Sp Br	45	1.0	Slight	S Rd-W
Sn			H Gr-W	0	S Ge Gr	10			S Rd-W	95	S Sp Gr	45			S Rd-W
Pb	00	Slight	H W	0	H Ge Gr-Br	0	0.0	Tight	S Gr	0	S Ge Br-Gr	5	2.0	Tight	S Gr-W
Zn			H W	0	H Ge Gr-Br	0			M Br-W	0	S Ge Gr	10			S W
Ni	00	Slight	VS Br	90	S Sp Gr-W	80	1.6	Tight	S Br	100	T - -	100	0.0	Tight	S Gr
Ni			VS Br	90	S Sp Gr-W	80			S Br	100	T -	100			S Gr
Ni	00	Slight	VS Br	90	S Ge Gr-Gn	10	1.0	Tight	S Br	100	S Sp Rd-Gr	20	1.0	Slight	S Br
Sn			M W-Br	80	S Ge Gr-Gn	10			S Gr-W	100	S Sp Rd-Gr	20			S W
Ni	Inf.	Slight	VH W	10	S Ge Gn-W	90	3.0	Tight	S Br	15	S Ge Gr	5	0.0	Tight	S Gr-W
Zn			VH W	0	M Ge Gr-W	0			S Br-Gr	5	S Ge Gr	5			S Gr-W
Sn	00	Slight	M Br-W	90	S Ge Gr	0	1.0	Slight	S Br	100	S Sp Gr	20	1.0	Slight	S Rd-W
Sn			M Br-W	90	S Ge Gr	0			S Br	100	S Sp Gr	20			S Rd-W
Sn	280	Slight	H W	0	H Ge Br-Gr	0	0.0	Tight	S Bk	90	S Ge Gr-Bl	10	1.0	Tight	S W
Zn			H W	0	H Ge Br-Gr	0			S Bk	0	S Sp Gr-Bl	5			S W
Zn	Inf.	Slight	VH W	0	M Ge Gr	0	0.0	Tight	S Bk	0	T - -	100	1.0	Tight	S W Gr
Zn			VH W	0	M Ge Gr	0			S Bk	0	T - -	100			S W Gr

* Deformed

TABLE IV. - CONTACT RESISTANCE AND VISUAL INSPECTION AFTER 7-YR. EXPOSURE.

Keywest, Fla.				Pittsburgh, Pa.						Altoona, Pa.						Rochester, N. Y.			
Edge Cor.Prod. Amt.Color	Paint Protection %	Face Cor. Prod. Amt.Dist.Color	Face Cor. Prod. % Not Cor.	Contact Res. Ohms	Edge Spread	Edge Cor.Prod Amt.Color	Paint Protection %	Face Cor. Prod. Amt.Dist.Color	Face Cor. Prod. % Not Cor.	Contact Res. Ohms	Edge Spread	Edge Cor.Prod Amt.Color	Paint Protection %	Face Cor. Prod. Amt.Dist.Color	Face Cor. Prod. % Not Cor.	Contact Res. Ohms	Edge Spread	Edge Cor.Prod Amt.Color	Paint Protection %
S Rd-W	100	M Ge Gr	5	0.0	Tight	S Bk	100	S Sp Gr	25	6.0	Tight	S Bk	100	M Ge Gr-Bk	10	1.0	Tight	S Bk	100
S Rd-W	100	M Ge Gr	5			S Bk	100	S Sp Gr	25			S Bk	100	M Ge Gr-Bk	10			S Bk	100
S Br-W	95	H Ge Gr-Gn	0	0.0	Tight	S Bk-W	100	T - -	100	Inf.	Wide	S Bk	100	H Ge Gr-Bk	0	11.0	Medium	S Bk	100
S Br-W	50	H Ge Gr-Bk	0			S Bk	110	T - -	100			S Bk	100	H Ge Gr-Bk	5			S Bk	100
M W-Br	100	H Ge Gr-Br	0	Inf.	Wide	S Bk	100	H Ge Br	0	Inf.	Wide	S Bk	100	H Ge Br-Bk	0	Inf.	Medium	S Bk	100
M Br	100	H Ge Gr-Br	0			H Br	0	H Ge Br	0			H Br	50	H Ge Br-Bk	0			H Br	0
S Br-W	100	H Ge Gr	5	2.0	Medium	S Bk	100	H Ge Gr-Bk	0	Inf.	Medium	S Bk	100	H Ge Gr-Bk	0	16 M	Tight	S Bk	100
S W	100	H Ge Gr*	0			S Gr	100	H Ge Gr-Bk	0			S Gr	100	H Ge Gr-Bk	0			S Bk	100
S Gr	100	M Ge Gr	0	1.0	Tight	S Bk	100	M Sp Gr-Gn	10	250.0	Tight	S Bk	100	M Sp Gn-Bk	20	10.0	Tight	S Bk	100
S Gr	100	M Sp Gr	40			S Bk	100	M Sp Gr-Bk	5			S Bk	100	M Sp Gr-Bk	20			S Bk	100
Rd-W	100	H Ge Gr	5	2.0	Medium	S Bk-W	100	H Ge Gr-Bk	0	23 M	Slight	S Bk-W	100	H Ge Gr-Bk	0	13 M	Medium	S Bk	100
S Rd-W	100	H Ge Gr	5			S Bk	100	H Ge Gr-Bk	0			S Bk	100	H Ge Gr-Bk	0			S Bk	100
S Gr	100	S Sp Gr	35	1.0	Tight	S Bk	100	S Sp Gr	20	1.0	Tight	S Bk	100	S Sp Gr	40	0.0	Tight	S Bk	100
S W-Gr	10	S Sp Gr	35			S Bk-W	100	S Ge Gr	5			Bk-W	100	S Sp Gr	10			S Bk-W	90
S Br	100	T - -	100	0.0	Tight	S Gn-Bk	100	T - -	100	0.0	Tight	S Bk-Gn	100	T - -	100	0.0	Tight	S Bk	100
S Br	100	T - -	100			S Gn-Bk	100	T - -	100			S Bk-Gn	100	T - -	100			S Bk	100
S Br	100	H Ge Br	0	2.0	Medium	S Bk	0	H Ge Br	0	80	Wide	S Bk	100	H Ge Br	0	Inf.	Slight	S Bk	100
H Br	100	H Ge Br	0			H Br	0	H Ge Br	0			H Br	0	H Ge Br	0			H Br	0
S Br	95	S Sp Gr	60	27.0	Slight	S Bk	100	S Ed Bk	75	30	Tight	S Bk-Gn	100	T - -	100	1.0	Slight	S Bk	100
S Br-Rd	95	S Sp Gr	60			S Bk	100	S Ed Bk	75			S Bk	100	S Ge Bl-Bk	75			S Bk	100
S Gr	95	T - -	100	0.0	Tight	S Bk	100	T - -	100	60	Tight	S Bk	100	T - -	100	0.0	Tight	S Bk	100
S Br	100	T - -	100			S Gn-Bk	100	T - -	100			S Bk	100	T - -	100			S Bk	100
S Br	90	S Ge Br	15	0.0	Slight	S Gn-Bk	100	M Sp Bk	30	32	Slight	S Bk	100	S Ge Rd-Bk	20	1.0	Slight	S Bk	100
S W	100	S Ge Br	5			S Bk	100	M Sp Bk	30			S Bk	100	M Ge Gr-Bk	10			S Bk	100
S Gr	0	S Ge Rd-Gn	0	2.0	Tight	S Bk	95	S Ge Gr	10	Inf.	Tight	S Bk	100	T - -	100	0.0	V.Sl't.	S Bk	60
S W	20	S Ge Br	0			S Bk-W	100	S. Ge Gr	10			S Bk-W	90	T - -	100			S Bk-W	25
M Br	95	H Ge Br	0	Inf.	Wide	H Br	0	H Ge Br	0	Inf.	Wide	H Br	0	H Ge Br	0	7 M	Tight	VH Br	0
M Br	100	H Ge Br	0			H Br	0	H Ge Br	0			H Br	0	H Ge Br	0			VH Br	0
S Br	100	H Ge Br	10	28.0	Wide	H Br	0	H Ge Br	10	1.0	Wide	H Br	0	H Ge Br-Bk	15	Inf.	Wide	VH Br	0
S Br-Gr	100	H Ge Br	10			S Bk	100	M Ge Br*	10			S Bk	100	H Ge Br-Bk*	15			S Bk	100
S Br-Bk	100	H Ge Br	0	Inf.	Wide	H Br	0	H Ge Br	0	Inf.	Tight	H Br	25	H Ge Br	10	Inf.	Tight	VH Br	0
S Br	100	H Ge Br	0			S Bk	10	M Ge Br	5			S Bk	100	H Ge Br	15			S Bk	100
M Br-Bk	100	H Ge Br	15	2.0	Wide	H Br	0	H Ge Br-Bk	5	2.0	Wide	H Br	0	H Ge Br-Bk	5	4 M	Wide	VH Br	0
S Br-W	100	H Ge Br*	15			S Bk	0	H Ge Br-Bk*	5			S Bk	100	H Ge Br-Bk*	5			S Bk	100
M Gr	70	S Ge Br	10	290M	Tight	S Bk	95	S Ge Br-Bk	10	Inf.	Medium	M Br	40	H Ge Br-Bk	15	2.0	Tight	S Bk	100
M Gr	60	S Ge Gr	2			S Bk-W	85	S Ge Gr-Bk	10			S Bk	100	H Ge Br-Bk	20			S Bk-W	95
S Rd-W	100	S Ge Gr	80	0.0	Slight	S Bk	100	S Sp Gr-Bk	40	0	Slight	S Bk	100	S Sp Gr	70	0.0	Slight	S Gr	100
S Rd-W	100	S Ge Gr	80			S Bk	100	S Sp Gr-Bk	40			S Bk	100	S Sp Gr	70			S Gr	100
S W	100	S Ge Gr	20	2.0	Slight	S Bk	100	S Ed Bk	40	3.0	Tight	S Bk	100	S Sp Gr	40	1.0	Slight	S Gr	100
S Gr	100	- -	100			S Bk	100	S Ed Bk	60			S Bk	100	S Sp Gr	40			S Bk	100
S Rd-W	100	M Sp Gr	20	0.0	Slight	S Bk	100	M Ed Gr-Bk	35	2.0	Slight	S Bk	100	S Sp Gr-Bk	20	2.0	Medium	S Bk	100
S Rd-W	100	S Sp Gr	40			S Bk	100	M Ed Gr-Bk	35			S Bk	100	S Sp Gr-Bk	20			S Bk	100
S Gr-W	80	S Ge Bl	10	1.0	Tight	S Bk	90	S Sp Gr	60	0	Tight	S Bk	100	S Sp Gr	85	3.0	Slight	M Bk	100
S W	70	S Ge Gr	25			S Bk-W	90	S Sp Gr	60			S Bk-W	100	S Sp Gr	90			M Bk-W	95
S Gr	100	T - -	100	0.0	Tight	S Br	90	T - -	100	0	Tight	S Bk	100	S Sp Gr	60	2.0	Tight	S Bk	100
S Gr	100	T - -	100			S Gr	100	T - -	100			S Bk	100	S Sp Gr	60			S Bk	100
S Br	100	T - -	100	0.0	Slight	S Br-Gr	90	S Ed Bk	75	0	Slight	S Bk-Gn	100	S Ed Gr-Bk	40	1.0	Slight	S Bk	100
S W	100	S Ge Gr	30			S Bk	100	S Ed Bk	75			S Bk	100	S Ed Gr-Bk	40			S Bk-Gr	100
S Gr-W	50	S Ge Bl	15	2.0	Tight	S Bk	95	S Sp Gr	30	16	Tight	S Bk	100	S Sp Gr	10	0.0	Tight	S Bk	100
S Gr-W	60	S Ge Bl-Gr	5			S Bk-W	90	S Sp Gr	20			S Bk-W	80	S Sp Gr	10			S Bk-Gr	95
S Rd-W	100	S Ge Br	20	0.0	Medium	S Bk	100	S Ed Bk	20	0	Slight	S Bk	100	M Sp Br-Bk	40	3.0	Slight	S Gr	100
S Rd-W	100	S Ge Br	20			S Bk	100	S Ed Bk	20			S Bk	100	M Sp Br-Bk	40			S Gr	100
S W	95	S Ge Gr	10	0.0	Tight	S Bk	95	S Sp Gr-Bk	40	1.0	Tight	S Bk	100	S Sp Gr	40	0.0	Slight	S Bk	100
S W	50	S Ge Gr	10			S Bk-W	90	S Sp Gr-Bk	40			S Bk-W	80	S Sp Gr	40			S Bk	100
S W Gr	10	S Sp Gr	25	Inf.	Slight	S Bk-W	50	S Sp Gr-Bk	25	3.0	Tight	S Bk-W	90	S Sp Gr-Bk	25	0.0	V.Sl't.	S Bk-Gr	100
S W Gr	20	S Sp Gr	25			S Bk-W	70	S Sp Gr-Bk	25			S Bk-W	95	S Sp Gr-Bk	25			S Bk-Gr	95

PLATE II
PROCEEDINGS, AM. SOC. T
VOL. 39
REPORT OF COMMIT
GALVANIC COUPLE CORR

, N. Y.			New York, N.Y.						State College, Pa.						Phoenix, Ariz.				
Paint Protection %	Face Cor. Prod.		Contact Res. Ohms	Edge Spread	Edge Cor.Prod. Amt.Color	Paint Protection %	Face Cor. Prod.		Contact Res. Ohms	Edge Spread	Edge Cor.Prod Amt.Color	Paint Protection %	Face Cor. Prod		Contact Res. Ohms	Edge Spread	Edge Cor.Prod Amt.Color	Paint Protection %	Face Cor. P
	Amt.Dist.Color	% Not Cor.					Amt.Dist.Color	% Not Cor.					Amt.Dist.Color	% Not Cor.					Amt.Dist.Color
100	S Sp Gr-Bl	60	0.0	Tight	S Bk-W	100	S Ge Bk-W	20			T -	100	T - -	100	0.0	Tight	T Gr	100	S Sp Gr
100	S Sp Gr-Bl	60			S Bk-W	100	S Ge Bk-W	20	0.0	Tight	T -	100	T - -	100			T Gr	100	S Sp Gr
100	H Ge Ge-Br	0	0.0	Medium	S Bk-W	100	H Ge Bl-W	0			T Br	100	S Ge Gn-Gr	20	0.0	Slight	S Gr	100	M Sp Gr-Gn
100	H Ge Ge-Br	0			S Bk	100	S Ge Bk-W	10	Inf.	V.Sl't.	T Br	100	S Ge Gr-Br	20			S Br	100	M Sp Gr-Br
100	H Ge Br	0	Inf.	Medium	S Bk-W	100	M Ge Br-W	0			S Br	100	H Ge Gr-Br	0	2.0	Slight	T Br	100	M Ge Gr-Br
0	H Ge Br	0			M Bk-Br	95	M Ge Br-W	0	1.0	Slight	S Br	95	H Ge Gr-Br	0			S Br	100	M Ge Gr-Br
100	S Sp Gr-Bl	25	0.0	Tight	S Bk-Br	100	M Ge Bk-W	0			T Bk	100	S Ge Gr	0	16.0	Slight	T W	100	S Ge Gr
100	S Sp Dark-Gr	50			S Bk	100	M Ge Bk-W	0	0.0	Tight	T W	100	S Ge Gr	0			T Bk	100	S Ge Gr
100	S Sp Gr	75	0.0	Wide	S Bk	100	S Sp Bk-Gn	10			T Br	100	T - -	100	1.0	Slight	T W	100	S Sp Gr
100	S Sp Gr	75			S Bk-Gr	100	S Sp Gr-Gn	25	70.0	Tight	T Br	100	T - -	100			T Br	100	S Sp Gr
100	H Ge Gr-Bl	0	0.0	Medium	S Bk-W	100	M Ge Bk-W	0			T Br	100	S Sp Gr	20	0.0	Slight	T Gr	100	S Sp Gr-Br
100	H Ge Gr-Bl	0			S Bk	100	M Ge Bk-W	0	0.0	Medium	S Br-W	100	S Sp Gr	20			T Gr	100	S Sp Gr-Br
100	S Sp Gr-Bl	85	0.0	Tight	S Bk-Gr	100	T - -	25			T Br	100	S Ge Gr	0	0.0	Tight	T Gr	100	S Ge Gr-Br
90	S Sp Gr-Bl	85			S Bk-W	20	S Ge Gr	10	0.0	Tight	T Br	100	S Ge Gr	0			T Gr	80	S Ge Gr-Br
100	T - -	100	0.0	Tight	S Bk-Gn	100	T - -	0			S Br	100	T - -	100	0.0	Tight	S Bk	100	T - -
100	T - -	100			S Bk-Gn	100	T - -	0	0.0	Tight	S Br	100	T - -	100			S Bk	100	T - -
100	H Ge Br	10	0.0	Medium	S Bk	0	M Ge Br	0			S Br	100	H Ge Br	5	0.0	Slight	S Br	100	S Ed Br
0	H Ge Br	10			H Br	0	M Ge Br	0	0.0	Medium	M Bk	95	H Ge Br	5			S Br	100	S Ed Br
100	S Ed Br	90	0.0	Tight	S Bk-Gr	100	T - -	0			T Br	100	T - -	100	0.0	Tight	S Bk	100	T - -
100	S Ed Br	90			S Bk	100	T - -	0	0.0	Tight	S Br-W	100	T - -	100			S Bk	100	T - -
100	S Ed Bl-Gr	90	0.0	Tight	S Bk	100	S Ge Gr-Rd	0			T Br	100	T - -	100	1.0	Tight	T Br	100	T - -
100	S Ed Br-Gr	90			S Bk	100	T - -	5	0.0	Tight	T Br	100	T - -	100			T -	100	T - -
100	M Sp Br	50	0.0	Tight	S Bk-Gr	100	S Ed Br	75			T Br	100	S Ed Br	50	0.0	Slight	S Bk	100	T - -
100	M Sp Br	50			S Bk	100	S Ed Br	75	0.0	Slight	S Br-W	100	S Ed Gr	50			T Gr	100	T - -
60	S Sp Gr-Br	85	0.0	Tight	S Bk-Gr	60	S Ed Bk-W	80			T Br-W	100	S Ed Pur	90	0.0	Tight	S Gr	85	T - -
25	S Sp Gr	85			S Bk-W	10	S Ed Gr	70	0.0	Tight	S Br	100	S Ed Gr	80			S Gr	90	T - -
0	H Ge Br	0	Inf.	Medium	H Br	0	H Ge Br	0			M Br-Bk	95	H Ge Br	0	450 M	Slight	S Br	100	M Ge Br
0	H Ge Br	0			H Br	0	H Ge Br	0	Inf.	Medium	M Br-Bk	95	H Ge Br	0			S Br	100	M Ge Br
0	H Sp Br	20	Inf.	Wide	H Br	0	H Ge Br	5			M Br-Bk	95	M Ed Br	30	0.0	Slight	S Br	100	S Ed Br
100	H Sp Br*	20			S Bk	0	S Ge Br	5	Inf.	Medium	S Br-W	100	M Ed Br	30			T Gr	100	S Ed Br
0	H Ge Br	0	Inf.	Slight	H Br	40	H Ge Br	0			M Br	95	H Ge Br	0	Inf.	Slight	S Br	100	M Ge Br
100	M Ge Br	5			S Bk	0	S Sp Br	5	Inf.	Medium	T Br	100	M Ge Br	0			S Br	100	M Ge Br
0	H Ge Br	5	0.0	Wide	H Br	20	H Ed Bk-Br	15			M Br-Bk	95	H Ge Br	0	0.0	Wide	S Br	100	M Ed Br
100	H Ge Br*	5			S Bk	0	H Ed Bk-Br	15	Inf.	Wide	S Br-W	95	M Ge Br*	0			S Br	100	M Ed Br
100	S Ge Br-Gr	10	0.0	Tight	S Bk	90	T - -	10			S Br	100	S Ed Br	40	Inf.	Tight	S Br	100	S Ed Br-G
95	S Ge Br-Gr	10			S Bk-W	50	S Ge Gr	0	Inf.	Tight	S Br	100	S Ed Br	50			T Gr	80	S Ed Br-G
100	S Ed Gr	90	0.0	Slight	S Bk	100	T - -	100			S W-Bk	100	S Sp Gr	50	0.0	Medium	S Bk	100	T - -
100	S Ed Gr	90			S Bk	100	T - -	100	0.0	Slight	S W-Bk	100	S Sp Gr	50			S Bk	100	T - -
100	S Ed Gr-Bl	75	Inf.	Slight	S Bk	100	T - -	40			S Bk-W	100	S Ed Gr	50	0.0	Tight	S Bk	100	T - -
100	S Ed Gr-Bl	75			S Bk	100	T - -	40	8.0	Slight	T Br	100	S Ed Gr	60			T Gr	100	T - -
100	S Ed Gr-Bl	75	0.0	Medium	S Bk	100	S Ed Bk-Br	30			S Bk	100	S Sp Gr	40		Medium	S Bk	100	T - -
100	S Ed Gr-Bl	75			S Bk-Gr	100	S Ed Br-Bl	30	0.0	Medium	S Gr	100	S Sp Gr	40	1.0		T Gr	100	T - -
100	S Sp Gr	85	0.0	Tight	S Bk-W	100	T - -	20			S Bk	100	S Sp Gr	50		Tight	S Gr	100	S Sp Gr
95	S Sp Gr	80			S Bk-W	50	T - -	10	0.0	Tight	S Bk	100	S Sp Gr	50	1.0		S Gr	90	S Sp Gr
100	T - -	100	0.0	Tight	S Bk-Gr	100	T - -	0			T Bk	100	T - -	100	0.0	Tight	T Gr	100	T - -
100	T - -	100			S Bk-Gr	100	T - -	0	0.0	Tight	T Bk	100	T - -	100			T Gr	100	T - -
100	S Sp Bl	60	120 M	Slight	S Bk-Gr	100	T - -	30			T Bk	100	S Sp Gr	50	0.0	Slight	S Gr	100	T - -
100	S Sp Bl	65			S Bk	100	T - -	30	0.0	Slight	S W	100	S Sp Gr	50			S Gr	100	T - -
100	S Sp Gr	50	240 M	Tight	S Bk	100	T - -	25			S Bk	100	S Sp Bl-W	50	2.0	Tight	T Gr	95	T - -
95	S Sp Gr	50			S Bk-W	10	T - -	25	230.0	Tight	S Br	100	S Sp Bl-W	50			T Gr	80	T - -
100	S Sp Gr	60	Inf.	Medium	S Bk	100	T - -	70			S W	100	S Sp Br	30	0.0	Medium	T Gr	100	T - -
100	H Ed Bl	60			S Bk	100	T - -	70	0.0	Medium	S W	100	S Sp Br	30			T Gr	100	T - -
100	S Sp Gr-Bl	50	240 M	Tight	S Bk	100	T - -	0			S Bk	100	S Ge Gr-Br	5	0.0	Tight	T Gr	100	T - -
100	S Sp Gr-Bl	50			S Bk-W	20	T - -	0	0.0	Slight	S Bk	100	S Ge Gr-Br	5			T Gr	80	T - -
100	S Sp Gr-Bl	80	0.0	Tight	S Bk-W	20	T - -	0			S Bk	95	S Sp Gr	30	0.0	Tight	T Gr	80	T - -
95	S Sp Gr-Bl	80			S Bk-W	20	T - -	0	480.0	Tight	S Bk	90	S Sp Gr	30			T Gr	80	T - -

REPORT OF COMMITTEE B-3:
GALVANIC COUPLE CORROSION TESTS

N.Y.			State College, Pa.						Phoenix, Ariz.						
aint ro-ec-ion %	Face Cor. Prod. Amt.Dist.Color	Face Cor. Prod. % Not Cor.	Contact Res. Ohms	Edge Spread	Edge Cor.Prod Amt.Color	Paint Protection %	Face Cor. Prod Amt.Dist.Color	Face Cor. Prod % Not Cor.	Contact Res. Ohms	Edge Spread	Edge Cor.Prod Amt.Color	Paint Protection %	Face Cor. Prod. Amt.Dist.Color	Face Cor. Prod. % Not Cor.	Couple
100	S Ge Bk-W	20			T -	100	T - -	100	0.0	Tight	T Gr	100	S Sp Gr	60	Al
100	S Ge Bk-W	20	0.0	Tight	T -	100	T - -	100			T Gr	100	S Sp Gr	60	Al
100	H Ge Bl-W	0			T Br	100	S Ge Gn-Gr	20	0.0	Slight	S Gr	100	M Sp Gr-Gn	20	Al
100	S Ge Bk-W	10	Inf.	V.Sl't.	T Br	100	S Ge Gr-Br	20			S Br	100	M Sp Gr-Br	20	Cu
100	M Ge Br-W	0			S Br	100	H Ge Gr-Br	0	2.0	Slight	T Br	100	M Ge Gr-Br	0	Al
95	M Ge Br-W	0	1.0	Slight	S Br	95	H Ge Gr-Br	0			S Br	100	M Ge Gr-Br	0	Fe
100	M Ge Bk-W	0			T Bk	100	S Ge Gr	0	16.0	Slight	T W	100	S Ge Gr	10	Al
100	M Ge Bk-W	0	0.0	Tight	T W	100	S Ge Gr	0			T Bk	100	S Ge Gr	10	Pb
100	S Sp Bk-Gn	10			T Br	100	T - -	100	1.0	Slight	T W	100	S Sp Gr	25	Al
100	S Sp Gr-Gn	25	70.0	Tight	T Br	100	T - -	100			T Br	100	S Sp Gr	25	Ni
100	M Ge Bk-W	0			T Br	100	S Sp Gr	20	0.0	Slight	T Gr	100	S Sp Gr-Br	20	Al
100	M Ge Bk-W	0	0.0	Medium	S Br-W	100	S Sp Gr	20			T Gr	100	S Sp Gr-Br	20	Sn
100	T - -	25			T Br	100	S Ge Gr	0	0.0	Tight	T Gr	100	S Ge Gr-Br	30	Al
20	S Ge Gr	10	0.0	Tight	T Br	100	S Ge Gr	0			T Gr	80	S Ge Gr-Br	30	Zn
100	T - -	0			S Br	100	T - -	100	0.0	Tight	S Bk	100	T - -	100	Cu
100	T - -	0	0.0	Tight	S Br	100	T - -	100			S Bk	100	T - -	100	Cu
0	M Ge Br	0			S Br	100	H Ge Br	5	0.0	Slight	S Br	100	S Ed Br	50	Cu
0	M Ge Br	0	0.0	Medium	M Bk	95	H Ge Br	5			S Br	100	S Ed Br	50	Fe
100	T - -	0			T Br	100	T - -	100	0.0	Tight	S Bk	100	T - -	100	Cu
100	T - -	0	0.0	Tight	S Br-W	100	T - -	100			S Bk	100	T - -	100	Pb
100	S Ge Gr-Rd	0			T Br	100	T - -	100	1.0	Tight	T Br	100	T - -	100	Cu
100	T - -	5	0.0	Tight	T Br	100	T - -	100			T -	100	T - -	100	Ni
100	S Ed Br	75			T Br	100	S Ed Br	50	0.0	Slight	S Bk	100	T - -	100	Cu
100	S Ed Br	75	0.0	Slight	S Br-W	100	S Ed Gr	50			T Gr	100	T - -	100	Sn
60	S Ed Bk-W	80			T Br-W	100	S Ed Pur	90	0.0	Tight	S Gr	85	T - -	100	Cu
10	S Ed Gr	70	0.0	Tight	S Br	100	S Ed Gr	80			S Gr	90	T - -	100	Zn
0	H Ge Br	0			M Br-Bk	95	H Ge Br	0	450 M	Slight	S Br	100	M Ge Br	0	Fe
0	H Ge Br	0	Inf.	Medium	M Br-Bk	95	H Ge Br	0			S Br	100	M Ge Br	0	Fe
0	H Ge Br	5			M Br-Bk	95	M Ed Br	30	0.0	Slight	S Br	100	S Ed Br	25	Fe
0	S Ge Br	5	Inf.	Medium	S Br-W	100	M Ed Br	30			T Gr	100	S Ed Br	25	Pb
40	H Ge Br	0			M Br	95	H Ge Br	0	Inf.	Slight	S Br	100	M Ge Br	0	Fe
0	S Sp Br	5	Inf.	Medium	T Br	100	M Ge Br	0			S Br	100	M Ge Br	0	Ni
20	H Ed Bk-Br	15			M Br-Bk	95	H Ge Br	0	0.0	Wide	S Br	100	M Ed Br	20	Fe
0	H Ed Bk-Br	15	Inf.	Wide	S Br-W	95	M Ge Br*	0			S Br	100	M Ed Br	20	Sn
90	T - -	10			S Br	100	S Ed Br	40	Inf.	Tight	S Br	100	S Ed Br-Gr	85	Fe
50	S Ge Gr	0	Inf.	Tight	S Br	100	S Ed Br	50			T Gr	80	S Ed Br-Gr	85	Zn
100	T - -	100			S W-Bk	100	S Sp Gr	50	0.0	Medium	S Bk	100	T - -	100	Pb
100	T - -	100	0.0	Slight	S W-Bk	100	S Sp Gr	50			S Bk	100	T - -	100	Pb
100	T - -	40			S Bk-W	100	S Ed Gr	50	0.0	Tight	S Bk	100	T - -	100	Pb
100	T - -	40	8.0	Slight	T Br	100	S Ed Gr	60			T Gr	100	T - -	100	Ni
100	S Ed Bk-Br	30			S Bk	100	S Sp Gr	40		Medium	S Bk	100	T - -	100	Pb
100	S Ed Br-Bl	30	0.0	Medium	S Gr	100	S Sp Gr	40	1.0		T Gr	100	T - -	100	Sn
100	T - -	20			S Bk	100	S Sp Gr	50		Tight	S Gr	100	S Sp Gr	80	Pb
50	T - -	10	0.0	Tight	S Bk	100	S Sp Gr	50	1.0		S Gr	90	S Sp Gr	80	Zn
100	T - -	0			T Bk	100	T - -	100	0.0	Tight	T Gr	100	T - -	100	Ni
100	T - -	0	0.0	Tight	T Bk	100	T - -	100			T Gr	100	T - -	100	Ni
100	T - -	30			T Bk	100	S Sp Gr	50	0.0	Slight	S Gr	100	T - -	100	Ni
100	T - -	30	0.0	Slight	S W	100	S Sp Gr	50			S Gr	100	T - -	100	Sn
100	T - -	25			S Bk	100	S Sp Bl-W	50	2.0	Tight	T Gr	95	T - -	100	Ni
10	T - -	25	230.0	Tight	S Br	100	S Sp Bl-W	50			T Gr	80	T - -	100	Zn
00	T - -	70			S W	100	S Sp Br	30	0.0	Medium	T Gr	100	T - -	100	Sn
00	T - -	70	0.0	Medium	S W	100	S Sp Br	30			T Gr	100	T - -	100	Sn
00	T - -	0			S Bk	100	S Ge Gr-Br	5	0.0	Tight	T Gr	100	T - -	100	Sn
20	T - -	0	0.0	Slight	S Bk	100	S Ge Gr-Br	5			T Gr	80	T - -	100	Zn
20	T - -	0			S Bk	95	S Sp Gr	30	0.0	Tight	T Gr	80	T - -	100	Zn
20	T - -	0	480.0	Tight	S Bk	90	S Sp Gr	30			T Gr	80	T - -	100	Zn

Removal of Paint and Corrosion Products:

After the inspection, the paint and corrosion products were removed by the following processes:

Iron.—The iron disks were immersed in a boiling solution of 20 per cent sodium hydroxide to which had been added 200 to 300 g. of zinc dust per liter. The disks were placed so that they were in contact with the zinc dust. They were rinsed in water periodically and scrubbed with a bristle brush until all the paint and corrosion products were removed. This treatment required from 30 min. to 2 hr. Blank iron disks subjected to this treatment for 2 hr. showed no loss in weight.

Nickel.—The paint was removed by a 10-min. dip in a hot 4 per cent sodium hydroxide solution. The corrosion products were removed by a 10-min. treatment in a solution of hydrochloric acid (1:1) containing 10 g. per liter of rodine at a temperature of 10 to 15 C. The disks were then scrubbed under running water. Blank disks subjected to these treatments showed a maximum loss in weight of 2.0 mg.

Aluminum.—All aluminum disks were cleaned in a solution of concentrated nitric acid at room temperature for periods varying from $\frac{1}{2}$ to 2 hr. Periodically they were rinsed and scrubbed under running water. With the exception of those disks coupled with tin or iron, this treatment was sufficient to remove paint and corrosion products. The disks coupled with tin or iron were subjected to an additional 20 min. treatment with a solution of hydrochloric acid (1:1) containing 10 g. per liter of rodine at a temperature of 0 to 5 C. Blank aluminum disks treated with nitric acid showed no loss in weight. The hydrochloric acid treatment caused a 4-mg. loss in weight.

Tin.—The paint from the tin disks was removed by a 10-min. dip in boiling 15 per cent trisodium phosphate. This treatment was sufficient also to remove the corrosion products from the tin disks coupled with zinc or nickel. The corrosion products from the disks coupled with copper, lead, aluminum, or tin were removed by a 10-min. treatment in a solution of hydrochloric acid (1:1) containing 10 g. per liter of rodine at a temperature of 10 to 15 C. The tin disks coupled with iron were treated for 30 min. in boiling 40 per cent ammonium acetate containing 10 g. per liter of rodine followed by a 10-min. dip in cold hydrochloric acid (1:1). This treatment removed rust which adhered to the tin disks. Blank specimens lost 1 mg. by the phosphate dip, 2 mg. by the hydrochloric acid treatment, and 5 mg. by the ammonuim acetate action.

Lead.—A 5-min. dip in boiling trisodium phosphate was used to remove the paint from the lead disks. They were then boiled in 1 per cent acetic acid for 10 min., but this treatment did not satisfactorily remove the corrosion products. The disks were then treated for 40 min. with a boiling 40 per cent solution of ammonium acetate containing 10 g. per liter of rodine and then rinsed in water. Removal of the corrosion products was aided by bending the disks and rubbing them lightly using rubber gloves. Blank lead disks subjected to this phosphate, acetic acid, and ammonium acetate treatment lost 1 mg., 5 mg. and 4 mg., respectively.

Zinc.—The zinc disks were treated for 10 min. with a 20 per cent solution of chromic acid at 80 C. During this treatment they were scrubbed periodically under running tap water to remove loosened paint and corrosion products. The chromic acid solution must contain little or no sulfate in order that the attack on the metal be slight. Since with use the solution became contaminated with sulfate, it was necessary to run periodic checks using blank zinc disks. A fresh solution was made when the blank loss became high. The average loss in weight by the blank disks was 7 mg. in 10 min.

Copper.—A 5 min. dip in a boiling solution of 4 per cent sodium hydroxide was used to remove the paint from the copper disks. The blank loss by this treatment was less than 1 mg. The disks were then immersed for 15 min. in a solution of hydrochloric acid (1:1) containing 10 g. per liter of rodine at a temperature of 10 to 15 C. and then rinsed in water. The copper disks coupled with iron were given an additional 25 min. treatment in the hydrochloric acid solution with occasional scrubbing under running water. Blank copper disks lost 7 mg. in 15 min. by the hydrochloric acid treatment.

Presentation of Data on Weight Changes:

After cleaning, the disks were weighed to the nearest milligram to determine the loss of metal by corrosion. The results, corrected for cleaning errors, are given in Table V (Plate III). The first column under each location gives the actual weight change of the disks in milligrams. The weight changes, expressed as percentages of the original weight of the disks, are given in the second column. The weight changes for the blanks are given at the head of each group of couples and the average for the blanks are given in parentheses in the third column. These values represent the normal corrosion of the metal, when assembled in the form of the test specimens. The third column also gives the weight difference between the normal corrosion and the corrosion of the metal concerned when coupled with other metals. The plus signs indicate acceleration, and the minus signs retardation, of the normal corrosion under the test conditions.

In several instances the final weight of the disk was higher than the original weight. These cases are shown by the asterisks on the table and are due to the incomplete removal of the corrosion products of the other metal in the couple. For example, in the case of the tin-aluminum couples the corrosion products of aluminum were imbedded in several of the tin disks and could not be removed by the cleaning method used. A careful inspection of the disks, showing an increase in weight, indicated that the corrosion of the metal was negligible, as recorded by the symbol *N* in the percentage columns.

Table VI (Plate IV) presents a summary of the results obtained in all three test periods. In this table the weight change data, expressed as a percentage of the original weight, are arranged in columns so as to permit an easy comparison of the results obtained in the the successive test periods. The percentages are given to the nearest 0.1 per cent, and values less than 0.06 per cent are considered as negligible.

The test results given in Table VI (Plate IV) are shown graphically in Figs. 3 and 4 (Plates V and VI). The data for all metals except iron, and all test locations except La Jolla, are plotted to the same scale in Fig. 3 (Plate V). The data obtained at La Jolla and for the iron disks at all locations are plotted to different scales in Fig. 4 (Plate VI). This arrangement was found necessary because of the relative amounts of corrosion involved.

In arranging the graphs, the results for the same metal are grouped together for each of the exposure locations, which are indicated at the bottom of the plate. The columns give the percentage weight changes of the respective metals when

TABLE V. - WEIGHT CHANGES A

CORROSION PRODUCT

Metal	When Coupled with	La Jolla, Calif.			Sandy Hook, N.J.			Key West, Fla.			Pittsburgh, Pa.			
		Weight Loss			Weight Loss			Weight Loss			Weight Loss			Wei
		mg.(a)	per cent (b)	Weight Diff., mg.(c)	mg.(a)	per cent (b)	Weight Diff., mg.(c)	mg.(a)	per cent (b)	Weight Diff., mg.(c)	mg.(a)	per cent (b)	Weight Diff., mg.(c)	mg.(a)
Aluminum	Blank	96	2.1	(104)	20	0.44	(20)	14	0.30	(13)	11	0.24	(11)	21
	"	113	2.5	-	21	0.46	-	12	0.26	-	10	0.22	-	19
	Copper	762	16.6	+ 658	357	7.8	+ 337	164	3.6	+ 151	44	0.95	+ 33	150
	Iron	382	8.3	+ 278	59	1.3	+ 39	123	2.7	+ 110	68	1.5	+ 57	90
	Lead	703	15.3	+ 599	135	2.9	+ 115	143	3.1	+ 130	86	1.9	+ 75	89
	Nickel	277	6.0	+ 173	39	0.85	+ 19	70	1.5	+ 57	27	0.6	+ 16	61
	Tin	428	9.4	+ 324	108	2.4	+ 88	74	1.6	+ 61	56	1.2	+ 45	66
	Zinc	28	0.6	- 76	10	0.22	- 10	1	N	- 14	2	0.04	- 9	4
Copper	Blank	339	2.3	(358)	25	0.17	(26)	26	0.18	(30)	58	0.39	(62)	47
	"	377	2.5	-	28	0.19	-	34	0.23	-	67	0.45	-	69
	Aluminum	37	0.25	- 321	49	0.33	+ 23	19	0.13	- 11	31	0.21	- 31	16
	Iron	89	0.60	- 269	50	0.34	+ 24	30	0.20	0	39	0.26	- 23	25
	Lead	47	0.32	- 311	24	0.16	- 2	14	0.09	- 16	81	0.55	+ 19	58
	Nickel	1268	8.5	+ 910	30	0.20	+ 4	13	0.09	- 17	9	0.06	- 51	16
	Tin	19	0.13	- 339	41	0.28	+ 15	20	0.13	- 10	98	0.66	+ 36	62
	Zinc	27	0.18	- 331	8	0.05	- 18	12	0.08	- 18	3	0.02	- 59	41
Iron	Blank	9547	74.7	(9547)	962	7.6	(966)	735	5.7	(750)	1798	14.0	(1825)	1377
	"	-	-	-	971	7.6	-	765	6.0	-	1853	14.5	-	1057
	Aluminum	5040	39.3	-4507	869	6.8	- 97	510	4.0	- 240	1952	15.2	+ 127	686
	Copper	7471	58.4	-2076	921	7.2	- 45	1394	10.9	+ 644	3178	24.8	+1353	1679
	Lead	5000	39.0	-4547	436	3.4	- 530	270	2.1	- 480	2011	15.8	+ 186	1229
	Nickel	-	-	-	743	5.8	- 223	825	6.5	+ 75	1903	14.9	+ 78	825
	Tin	6751	52.8	-2796	1202	9.4	+ 236	541	4.3	- 209	2591	20.2	+ 766	1625
	Zinc	714	5.6	-8833	156	1.2	- 810	11	0.09	- 739	43	0.34	-1782	546
Lead	Blank	126	0.68	(115)	56	0.28	(62)	189	0.97	(192)	93	0.47	(87)	82
	"	104	0.55	-	69	0.35	-	194	1.1	-	83	0.47	-	63
	Aluminum	117	0.59	+ 2	93	0.48	+ 31	176	0.9	- 15	140	0.79	+ 53	87
	Copper	518	2.8	+ 403	104	0.53	+ 42	205	1.1	+ 14	103	0.52	+ 16	90
	Iron	284	1.5	+ 169	110	0.56	+ 58	276	1.3	+ 85	121	0.62	+ 34	102
	Nickel	380	1.9	+ 265	88	0.45	+ 26	227	1.2	+ 36	135	0.69	+ 48	73
	Tin	187	0.95	+ 72	95	0.49	+ 33	205	1.1	+ 14	107	0.54	+ 20	69
	Zinc	479	2.4	+ 364	129	0.66	+ 67	223	1.2	+ 32	135	0.68	+ 48	77
Nickel	Blank	4	0.03	(6)	13	0.09	(14)	0.0	0.0	(0.0)	75	0.50	(67)	66
	"	7	0.03	-	15	0.10	-	0.0	0.0	-	58	0.38	-	56
	Aluminum	4	0.03	- 2	16	0.11	+ 2	3*	N	0	25	0.17	- 42	44
	Copper	5	0.03	- 1	7	0.05	- 7	0.0	0.0	0.0	170	1.1	+ 103	103
	Iron	Missing		-	26	0.17	+ 12	6	0.04	+ 6	83	0.55	+ 16	51
	Lead	0	0.0	- 6	6	0.04	- 8	1*	N	0	80	0.54	+ 13	59
	Tin	0	0.0	- 6	21	0.19	+ 7	1*	N	0	106	0.71	+ 4	83
	Zinc	0	0.0	- 6	0	0.0	- 14	3*	N	0	0	0.0	- 67	5
Tin	Blank	75	0.61	(119)	36	0.29	(38)	28	0.23	(30)	58	0.47	(58)	37
	"	163	1.3	-	40	0.32	-	31	0.25	-	57	0.46	-	38
	Aluminum	20	0.16	- 99	32*	N	- 38	20*	N	- 30	5	0.04	- 53	4*
	Copper	496	4.0	+ 377	152	1.2	+ 114	350	2.8	+ 221	127	1.0	+ 69	102
	Iron	476	3.9	+ 357	125	1.0	+ 87	334	2.7	+ 305	76	0.62	+ 18	78
	Lead	52	0.42	- 67	28	0.23	- 10	19	0.15	- 10	68	0.55	+ 10	37
	Nickel	342	2.8	+ 223	34	0.28	- 4	35	0.29	+ 5	16	0.13	- 42	33
	Zinc	110	0.89	- 9	2	0.02	- 36	0.0	0.0	- 30	2	0.02	- 56	2
Zinc	Blank	1277	10.7	(1309)	93	0.78	(98)	96	0.80	(86)	203	1.7	(187)	190
	"	1342	11.3	-	103	0.86	-	77	0.59	-	171	1.4	-	160
	Aluminum	1870	15.6	+ 461	248	2.1	+ 150	219	1.8	+ 133	362	3.0	+ 175	353
	Copper	2494	21.0	+1185	258	2.2	+ 160	144	1.2	+ 58	292	2.5	+ 105	283
	Iron	2718	22.8	+1409	252	2.1	+ 154	172	1.4	+ 86	332	2.8	+ 145	220
	Lead	2752	23.1	+1443	204	1.7	+ 106	123	1.0	+ 37	313	2.6	+ 126	349
	Nickel	3850	32.2	+2541	275	2.3	+ 177	277	2.3	+ 191	343	2.9	+ 156	378
	Tin	2340	19.6	+1031	196	1.6	+ 98	124	1.0	+ 38	309	2.6	+ 122	279

(a) Weight change of disks in milligrams.
(b) Weight change of disks in per cent of original weight.
(c) Difference between average weight change of each metal coupled with itself and when coupled with other metal.

+ Corrosion accelerated.
- Corrosion retarded.
( ) Figures in parentheses give the average weight ch
disks of the same metal coupled together.

PLATE III
PROCEEDINGS, AM. SOC. TESTING MATS.
VOL. 39
REPORT OF COMMITTEE B-3:
GALVANIC COUPLE CORROSION TESTS

ANGES AFTER 7-YR. EXPOSURE.

PRODUCTS REMOVED.

Altoona, Pa.			Rochester, N.Y.			New York, N.Y.			State College, Pa.			Phoenix, Ariz.		
Weight Loss			Weight Loss			Weight Loss			Weight Loss			Weight Loss		
mg. (a)	per cent (b)	Weight Diff., mg. (c)	mg. (a)	per cent (b)	Weight Diff., mg. (c)	mg. (a)	per cent (b)	Weight Diff., mg. (c)	mg. (a)	per cent (b)	Weight Diff., mg. (c)	mg. (a)	per cent (b)	Weight Diff., mg. (c)
21	0.46	(20)	6	0.13	(6)	18	0.39	(20)	2	0.04	(2)	4	0.09	(3)
19	0.42	-	6	0.13	-	22	0.48	-	1	0.02	-	2	0.04	-
150	3.3	+ 130	184	4.0	+ 178	214	4.8	+ 194	23	0.50	+ 21	38	0.82	+ 35
90	2.0	+ 70	78	1.7	+ 72	203	4.4	+ 183	64	1.4	+ 62	64	1.4	+ 61
89	1.9	+ 69	20	0.44	+ 14	99	2.2	+ 79	17	0.37	+ 15	19	0.41	+ 16
61	1.3	+ 41	10	0.22	+ 4	59	1.3	+ 39	13	0.28	+ 11	6	0.13	+ 3
66	1.4	+ 46	45	0.99	+ 39	84	1.8	+ 64	13	0.28	+ 11	6	0.13	+ 3
4	0.09	- 16	3	0.07	- 3	2	0.04	- 18	0	0.0	- 2	1	0.02	- 2
47	0.32	(58)	30	0.20	(31)	51	0.34	(50)	20	0.13	(16)	11	0.07	(10)
69	0.46	-	33	0.22	-	48	0.32	-	12	0.08	-	8	0.05	-
16	0.11	- 42	18	0.12	- 13	19	0.13	- 31	12	0.08	- 4	2	0.01	- 8
25	0.17	- 33	16	0.11	- 15	31	0.21	- 19	19	0.13	+ 3	16	0.11	+ 6
58	0.39	0	44	0.30	+ 13	65	0.44	+ 15	6	0.04	- 10	8	0.05	- 2
16	0.11	- 42	12	0.08	- 19	35	0.24	- 15	16	0.11	0	5	0.03	- 5
62	0.42	+ 4	48	0.32	+ 17	60	0.40	+ 10	12	0.08	- 4	5	0.03	- 5
41	0.28	- 17	1	0.01	- 30	1	0.01	- 49	1*	N	- 16	1*	N	- 10
1377	10.8	1217	1358	10.7	(1406)	1545	12.1	(1534)	469	3.7	(470)	148	1.15	(136)
1057	8.2	-	1454	11.4	-	1524	11.9	-	470	3.7	-	125	0.98	-
686	5.4	- 531	1483	11.6	+ 77	1000	7.8	- 534	284	2.2	- 186	40	0.31	- 96
1679	13.2	+ 462	2059	16.2	+ 653	1876	14.6	+ 342	641	5.0	+ 171	152	1.2	+ 16
1229	9.6	+ 12	1938	15.2	+ 532	1497	11.7	- 37	291	2.3	- 179	97	0.76	- 39
825	6.4	- 392	1595	12.5	+ 189	1091	8.5	- 443	500	3.9	+ 30	145	1.1	+ 9
1625	12.8	+ 408	2081	16.2	+ 675	1706	13.4	+ 172	569	4.4	+ 99	190	1.5	+ 54
546	4.3	- 671	6	0.05	-1400	5	0.04	-1529	147	1.2	- 323	9	0.07	- 127
82	0.42	(72)	105	0.54	(95)	86	0.43	(76)	74	0.38	(76)	75	0.40	(79)
63	0.35	-	86	0.44	-	66	0.35	-	79	0.40	-	84	0.43	-
87	0.44	+ 15	74	0.37	- 21	81	0.41	+ 5	93	0.48	+ 17	102	0.54	+ 23
90	0.48	+ 18	95	0.50	0	85	0.42	+ 9	97	0.49	+ 21	94	0.48	+ 15
102	0.52	+ 30	136	0.69	+ 41	81	0.43	+ 5	119	0.58	+ 43	98	0.50	+ 19
73	0.39	+ 1	115	0.61	+ 20	71	0.36	- 5	95	0.48	+ 19	67	0.34	- 12
69	0.35	- 3	86	0.44	- 9	65	0.32	- 11	90	0.44	+ 14	71	0.36	- 8
77	0.37	+ 5	98	0.52	+ 3	88	0.44	+ 12	104	0.53	+ 28	85	0.46	+ 6
66	0.43	(61)	17	0.11	(16)	63	0.42	(61)	2	0.01	(2)	1*	N	(2)
56	0.37	-	15	0.10	-	59	0.39	-	3	0.02	-	4	0.03	-
44	0.29	- 17	5	0.03	- 11	42	0.28	- 19	4	0.03	+ 2	2*	N	- 2
103	0.68	+ 42	48	0.32	+ 32	91	0.60	+ 30	1*	N	- 2	2*	N	- 2
51	0.34	- 10	27	0.18	+ 11	49	0.32	- 12	1	0.01	- 1	1*	N	- 2
59	0.39	- 2	26	0.17	+ 10	54	0.37	- 7	1*	N	- 2	1*	N	- 2
83	0.55	+ 22	30	0.20	+ 14	81	0.54	+ 20	4	0.03	+ 2	1*	N	- 2
5	0.03	- 56	3*	N	- 16	35	0.23	- 26	1*	N	- 2	2*	N	- 2
37	0.30	(37)	24	0.20	(23)	33	0.27	(34)	12	0.10	(12)	9	0.07	(9)
38	0.31	-	21	0.17		35	0.29	-	13	0.11	-	9	0.07	-
4*	N	- 37	2	0.02	- 21	10*	N	- 34	2	0.02	- 10	1	0.01	- 8
102	0.82	+ 65	68	0.55	+ 45	77	0.62	+ 43	28	0.23	+ 16	31	0.25	+ 22
78	0.63	+ 41	47	0.38	+ 24	72	0.59	+ 38	48	0.39	+ 36	54	0.43	+ 45
37	0.30	0	21	0.17	- 2	36	0.30	+ 2	1	0.01	- 11	2	0.02	- 7
33	0.27	- 4	12	0.10	- 11	21	0.17	- 13	16	0.13	+ 4	10	0.08	+ 1
2	0.02	- 35	0	0	- 23	0	0.0	- 34	2*	N	- 12	1	0.01	- 8
190	1.6	(175)	43	0.36	(43)	196	1.6	(195)	27	0.23	(27)	11	0.09	(10)
160	1.3	-	44	0.37	-	194	1.6	-	28	0.23	-	9	0.08	-
353	3.0	+ 178	141	1.2	+ 98	440	3.7	+ 245	100	0.84	+ 73	73	0.61	+ 63
283	2.4	+ 108	100	0.84	+ 57	338	2.8	+ 143	48	0.40	+ 21	28	0.23	+ 18
220	1.9	+ 45	127	1.1	+ 84	349	2.9	+ 154	81	0.68	+ 54	41	0.34	+ 31
349	2.9	+ 174	83	0.69	+ 55	328	2.7	+ 133	47	0.40	+ 20	23	0.19	+ 13
378	3.2	+ 203	146	1.2	+ 103	395	3.3	+ 200	104	0.87	+ 77	114	0.95	+ 104
279	2.3	+ 104	83	0.70	+ 40	269	2.3	+ 74	61	0.51	+ 34	70	0.59	+ 60

eight change in

* Indicates that the final weight of the disk was more than the initial weight. Inspection of these disks showed that the corrosion was negligible.

N Weight change, negligible.

TABLE VI. - WEIGHT LOSS OF DISK

1, 3 AND 7-YR.

Metal	Couple With	La Jolla, Calif.			Sandy Hook, N.J.			Key West, Fla.			Pittsburgh, Pa.		
		1 yr.	3 yr.	7 yr.	1 yr.	3 yr.	7 yr.	1 yr.	3 yr.	7 yr.	1 yr.	3 yr.	7 yr.
Aluminum	Aluminum	0.4	1.1	2.3	N	0.2	0.5	0.1	0.3	0.3	N	0.1	0.2
	Copper	5.2	10.1	16.6	0.8	4.4	7.8	1.0	3.1	3.6	N	0.2	1.0
	Iron	2.7	*	8.3	0.1	*	1.3	0.8	*	2.7	N	*	1.5
	Lead	N	4.7	15.3	0.2	1.9	2.9	0.1	1.6	3.1	N	0.1	1.9
	Nickel	2.5	6.2	6.0	N	0.9	0.8	0.3	1.1	1.5	N	0.2	0.6
	Tin	1.4	4.6	9.4	0.1	1.1	2.4	0.2	1.1	1.6	N	0.2	1.2
	Zinc	0.3	0.2	0.6	N	N	0.2	N	N	N	N	N	N
Copper	Copper	0.5	0.9	2.4	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.3	0.4
	Aluminum	0.2	0.3	0.2	0.1	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.2
	Iron	0.4	0.8	0.6	0.2	0.2	0.3	0.2	0.1	0.2	0.2	0.3	0.3
	Lead	0.1	0.3	0.3	0.1	N	0.2	0.1	0.1	0.1	N	0.3	0.5
	Nickel	1.2	2.9	8.5	0.1	0.1	0.2	0.1	0.1	0.1	N	N	0.1
	Tin	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.3	0.7
	Zinc	0.2	0.2	0.2	0.1	0.1	N	0.1	0.1	0.1	N	N	N
Iron	Iron	8.8	23.0	74.7	1.7	4.0	7.6	1.8	3.7	5.8	3.0	5.9	14.2
	Aluminum	4.9	9.8	39.3	2.0	4.7	6.8	0.8	2.4	4.0	3.2	3.3	15.2
	Copper	16.0	33.3	58.4	2.7	5.1	7.2	2.5	6.4	10.9	4.6	10.2	24.8
	Lead	8.2	21.9	39.0	1.0	3.0	3.4	0.8	1.7	2.1	3.3	6.9	15.8
	Nickel	11.8	23.3	*	1.8	4.2	5.8	2.4	4.4	6.5	4.4	6.8	14.9
	Tin	10.3	18.4	52.8	1.6	4.0	9.4	0.6	2.2	4.3	3.6	8.7	20.2
	Zinc	0.8	3.9	5.6	0.1	0.1	1.2	0.1	0.1	0.1	0.2	0.2	0.3
Lead	Lead	0.2	0.5	0.6	0.1	0.2	0.3	0.1	0.5	1.0	0.1	0.2	0.5
	Aluminum	0.1	0.4	0.6	0.1	0.2	0.5	0.4	0.4	0.9	0.2	0.2	0.8
	Copper	1.4	1.5	2.8	0.2	0.2	0.5	0.3	0.6	1.1	0.2	0.2	0.5
	Iron	N	0.8	1.5	0.2	0.4	0.6	0.3	0.7	1.3	0.2	0.4	0.6
	Nickel	0.4	1.1	1.9	0.1	0.2	0.4	0.2	0.6	1.2	0.2	0.4	0.7
	Tin	0.2	0.4	0.9	0.2	0.2	0.5	0.4	0.6	1.1	0.1	0.2	0.5
	Zinc	1.1	1.5	2.4	0.1	0.4	0.7	0.2	0.5	1.2	0.1	0.2	0.7
Nickel	Nickel	0.1	N	N	0.1	N	0.1	N	N	N	0.1	0.2	0.4
	Aluminum	0.1	N	N	N	0.1	0.1	N	N	N	0.1	0.1	0.2
	Copper	N	N	N	N	N	N	N	N	N	0.2	0.5	1.1
	Iron	0.2	0.2	*	0.1	0.1	0.2	N	N	N	0.2	0.3	0.5
	Lead	N	N	N	N	N	N	N	N	N	N	0.2	0.5
	Tin	N	N	N	N	N	0.2	N	N	N	N	0.2	0.7
	Zinc	0.1	N	N	N	N	N	N	N	N	0.2	N	N
Tin	Tin	0.2	0.3	1.0	0.1	0.1	0.3	0.1	0.2	0.2	0.1	0.1	0.5
	Aluminum	0.1	0.3	0.2	0.1	-	N	0.1	N	N	N	N	N
	Copper	1.4	2.9	4.0	0.2	0.4	1.2	0.3	0.9	2.8	0.2	0.5	1.0
	Iron	0.2	2.8	3.9	0.2	0.5	1.0	0.2	1.3	2.7	0.2	0.4	0.6
	Lead	0.1	0.3	0.4	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.5
	Nickel	0.3	1.1	2.8	0.1	0.2	0.3	0.1	0.1	0.3	0.2	0.1	0.1
	Zinc	0.1	0.2	0.9	0.1	0.1	N	N	N	N	N	N	N
Zinc	Zinc	1.5	3.5	11.0	0.1	0.3	0.8	0.2	0.3	0.7	0.2	0.5	1.5
	Aluminum	2.6	5.8	15.6	0.2	0.5	2.1	0.2	0.4	1.8	0.3	0.7	3.0
	Copper	3.9	8.0	21.0	0.3	0.8	2.2	0.3	0.6	1.2	0.3	0.9	2.5
	Iron	3.8	8.9	22.8	0.3	0.8	2.1	0.3	0.8	1.4	0.5	1.0	2.8
	Lead	4.2	11.0	23.1	0.2	1.5	1.7	0.2	0.4	1.0	0.3	0.9	2.6
	Nickel	3.8	12.5	32.2	0.2	0.6	2.3	0.3	0.5	2.3	0.3	0.8	2.9
	Tin	2.6	7.1	19.6	0.1	0.5	1.6	0.3	0.4	1.0	0.3	0.7	2.6

Note.- Weight losses given to the nearest 0.1 per cent.
N = Corrosion negligible, less than (0.06 per cent).
* = Disks missing.

PLATE IV
PROCEEDINGS, AM. SOC. TESTING MATS.
VOL. 39
REPORT OF COMMITTEE B-3:
GALVANIC COUPLE CORROSION TESTS

OF DISKS IN PER CENT OF ORIGINAL WEIGHT

D 7-YR. EXPOSURES.

Pa.	Altoona, Pa.			Rochester, N.Y.			New York, N.Y.			State College, Pa.			Phoenix, Ariz.		
7 yr.	1 yr.	3 yr.	7 yr.	1 yr.	3 yr.	7 yr.	1 yr.	3 yr.	7 yr.	1 yr.	3 yr.	7 yr.	1 yr.	3 yr.	7 yr.
0.2	N	0.2	0.4	N	N	0.1	N	0.1	0.4	N	N	N	N	N	0.1
1.0	0.1	1.7	3.3	N	0.2	4.0	0.2	2.2	4.8	N	0.2	0.5	N	0.2	0.8
1.5	0.2	*	2.0	0.1	*	1.7	0.5	*	4.4	N	*	1.4	N	*.	1.4
1.9	N	1.2	1.9	N	0.1	0.4	0.1	0.2	2.2	N	N	0.4	N	N	0.4
0.6	0.1	1.0	1.3	0.1	0.1	0.2	0.2	0.5	1.3	N	0.2	0.3	N	N	0.1
1.2	N	0.5	1.4	N	N	1.0	0.1	0.6	1.8	N	N	0.3	N	N	0.1
N	N	0.1	0.1	N	N	0.1	N	N	N	N	N	N	N	N	N
0.4	0.1	0.2	0.4	0.1	0.1	0.2	0.1	0.2	0.3	N	N	0.1	0.1	N	0.1
0.2	0.1	N	0.1	0.1	0.1	0.1	0.1	0.1	0.1	N	N	0.1	N	N	N
0.3	0.2	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.2	N	0.1	0.1	N	N	0.1
0.5	N	0.2	0.4	0.1	0.1	0.3	0.1	0.2	0.4	N	N	N	N	N	N
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	N	N	0.1	N	N	N
0.7	0.1	0.2	0.4	0.1	0.1	0.3	N	0.1	0.4	N	N	0.1	N	N	N
N	0.1	N	0.3	0.2	N	N	N	0.1	N	N	N	N	N	N	N
14.2	1.7	3.7	9.5	1.9	3.7	11.0	2.6	4.8	12.0	0.5	1.5	3.7	0.3	0.3	1.1
15.2	1.0	3.1	5.4	1.6	2.5	11.6	1.8	6.1	7.8	0.6	1.4	2.2	0.2	0.3	0.3
24.8	1.6	5.3	13.2	1.6	3.4	16.2	2.6	6.5	14.6	0.5	1.7	5.0	0.2	0.3	1.2
15.8	1.5	3.4	9.6	1.8	5.4	15.2	2.5	4.9	11.7	0.4	1.0	2.3	0.2	0.3	0.8
14.9	2.0	4.0	6.4	2.5	3.8	12.5	2.8	6.4	8.5	0.8	2.0	3.9	0.2	0.4	1.1
20.2	2.0	4.5	12.8	2.7	5.6	16.2	3.2	6.0	13.4	0.8	2.4	4.4	0.4	0.5	1.6
0.3	0.1	0.1	4.3	0.1	N	N	N	N	N	0.3	0.5	1.2	N	N	0.1
0.5	0.1	0.1	0.4	0.1	0.2	0.5	0.1	0.1	0.4	0.2	0.1	0.4	0.2	0.3	0.4
0.8	0.3	0.2	0.4	0.1	0.2	0.4	0.1	0.2	0.4	0.1	0.2	0.5	0.1	0.3	0.5
0.5	0.1	0.2	0.5	0.2	0.2	0.5	0.1	0.2	0.4	0.1	0.2	0.5	0.2	0.2	0.5
0.6	0.1	0.3	0.5	0.2	0.4	0.7	0.1	0.3	0.4	0.1	0.4	0.6	0.1	0.2	0.5
0.7	0.1	0.1	0.4	0.1	0.3	0.6	0.2	0.3	0.4	0.1	0.2	0.5	0.1	0.2	0.3
0.5	0.1	0.3	0.3	0.2	0.2	0.4	0.1	0.2	0.3	0.1	0.2	0.4	0.2	0.2	0.4
0.7	0.1	0.1	0.4	0.1	0.2	0.5	0.1	0.1	0.4	0.1	0.2	0.5	0.1	0.2	0.5
0.4	0.1	0.2	0.4	0.1	0.1	0.1	0.1	0.2	0.4	N	N	N	N	N	N
0.2	N	0.1	0.3	N	-	N	N	0.1	0.3	N	N	N	N	N	N
1.1	0.1	0.2	0.7	N	N	0.3	0.2	0.3	0.6	N	N	N	N	N	N
0.5	0.1	0.1	0.3	N	N	0.2	0.1	0.2	0.3	N	N	N	N	N	N
0.5	N	0.1	0.4	0.1	0.1	0.2	N	0.2	0.4	N	N	N	N	N	N
0.7	N	0.2	0.5	N	0.1	0.2	N	0.2	0.5	N	N	N	N	N	N
N	N	N	N	N	N	N	N	N	0.2	N	N	N	N	N	N
0.5	0.1	0.1	0.3	0.1	0.1	0.2	0.1	0.1	0.3	0.1	N	0.1	N	N	0.1
N	0.1	N	N	0.1	N	N	0.1	N	N	0.1	N	N	N	N	N
1.0	0.2	0.4	0.8	0.1	0.2	0.5	0.2	0.3	0.6	0.1	N	0.2	N	0.1	0.2
0.6	0.2	0.3	0.6	0.2	0.2	0.4	0.2	0.2	0.6	0.1	0.1	0.4	N	0.1	0.4
0.5	0.1	0.1	0.3	0.1	N	0.2	0.1	0.1	0.3	0.1	N	N	N	N	N
0.1	0.1	0.1	0.3	0.1	N	0.1	0.1	0.2	0.2	0.1	N	0.1	N	N	0.1
N	0.1	N	N	N	N	N	N	N	N	N	N	N	N	N	N
1.5	0.1	0.5	1.4	0.1	0.2	0.4	0.1	0.5	1.6	0.1	0.1	0.2	0.1	0.1	0.1
3.0	0.2	0.5	3.0	0.1	0.2	1.2	0.2	0.7	3.7	0.1	0.2	0.8	0.1	0.1	0.6
2.5	0.2	0.7	2.4	0.2	0.3	0.8	0.3	0.8	2.8	0.1	0.2	0.4	0.1	0.1	0.2
2.8	0.2	0.9	1.9	0.2	0.4	1.1	0.3	0.9	2.9	0.2	0.5	0.7	0.2	0.2	0.3
2.6	0.3	0.8	2.9	0.2	0.3	0.7	0.3	0.8	2.7	0.1	0.1	0.4	0.1	0.1	0.2
2.9	0.2	0.7	3.2	0.2	0.3	1.2	0.4	0.7	3.3	0.1	0.1	0.9	0.1	0.1	0.9
2.6	0.3	0.7	2.3	0.2	0.2	0.7	0.4	0.7	2.3	0.2	0.2	0.5	0.2	0.1	0.6

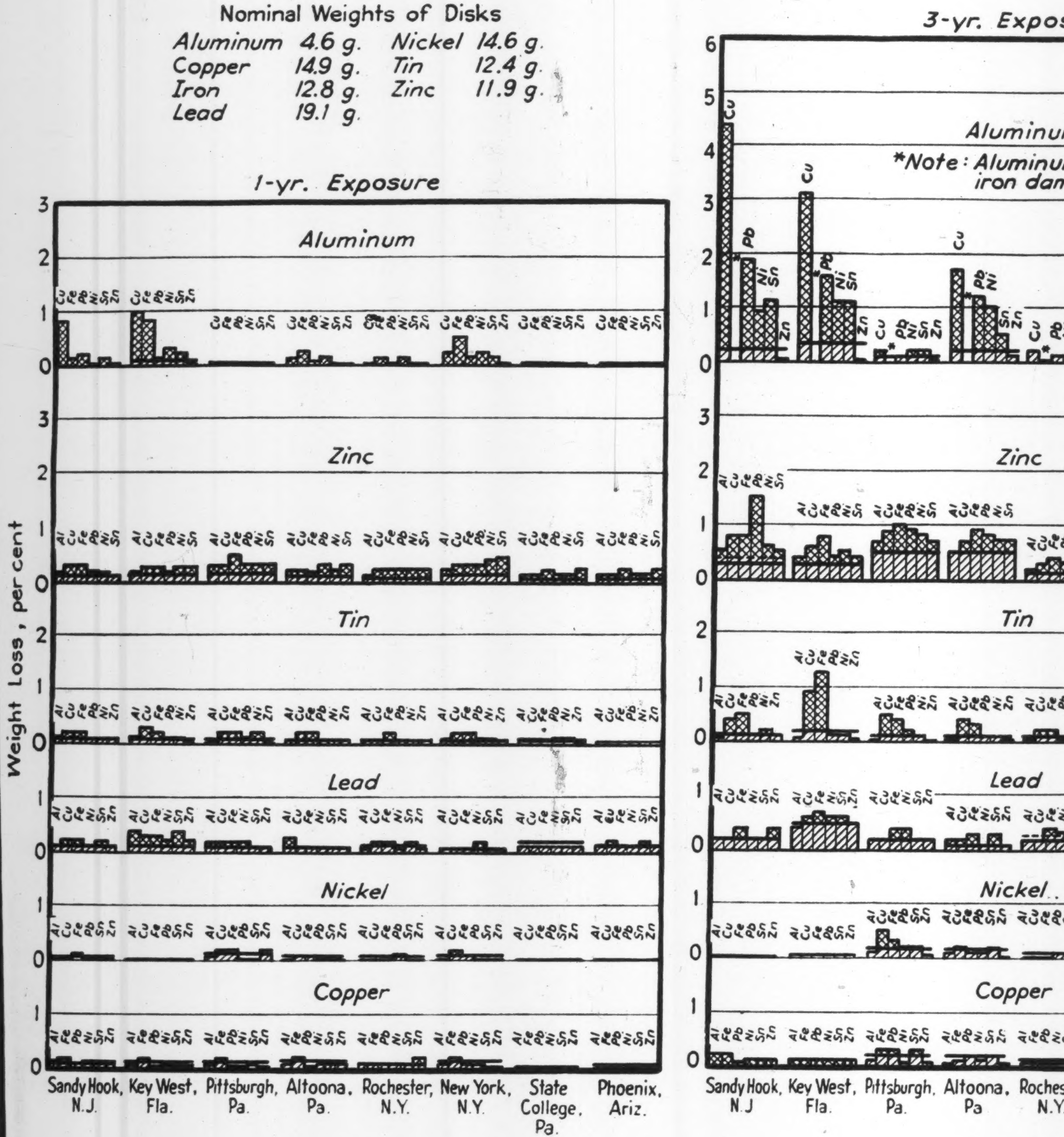

FIG. 3.—Weight Loss of

PLATE V
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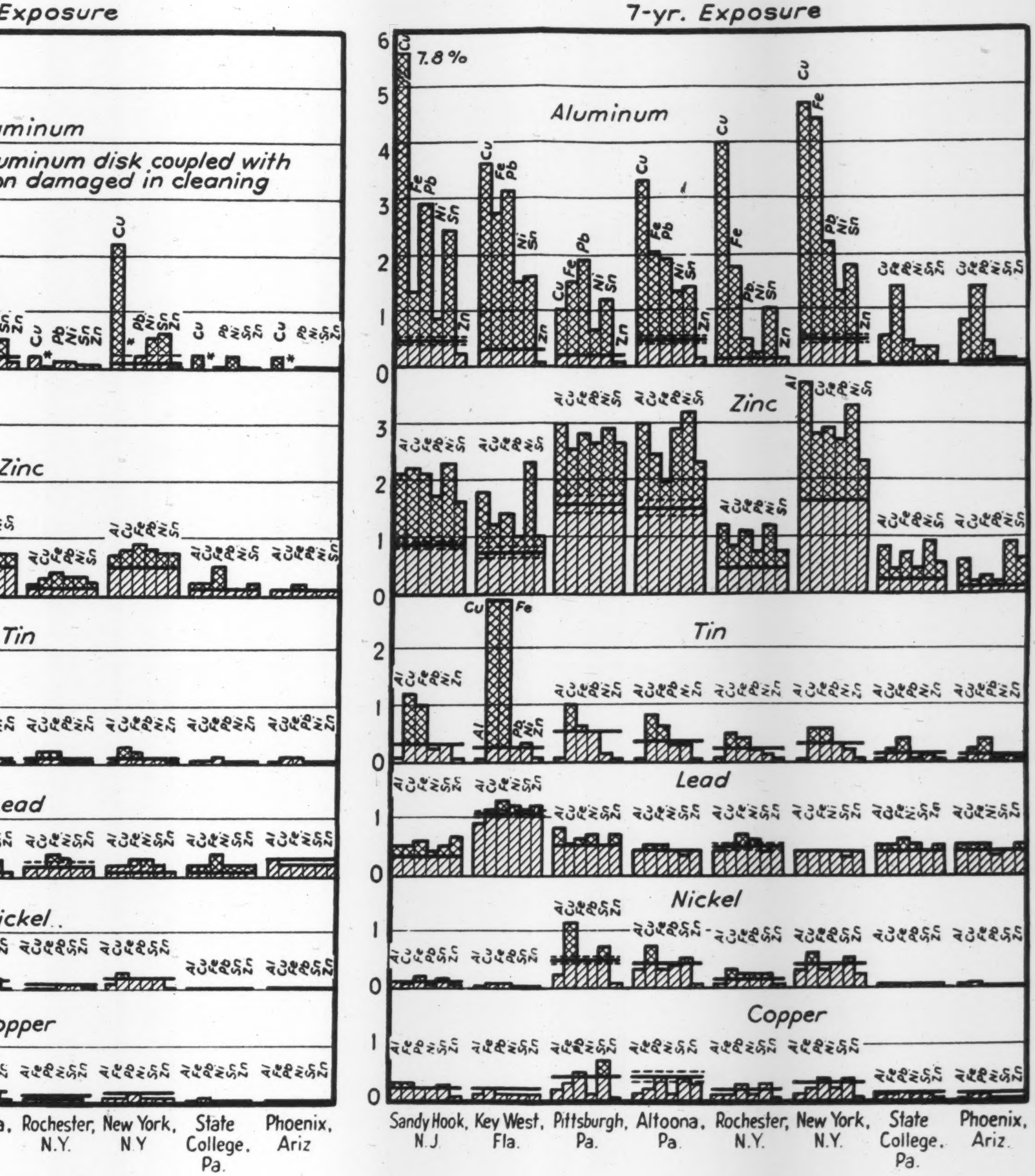


Loss of Disks.

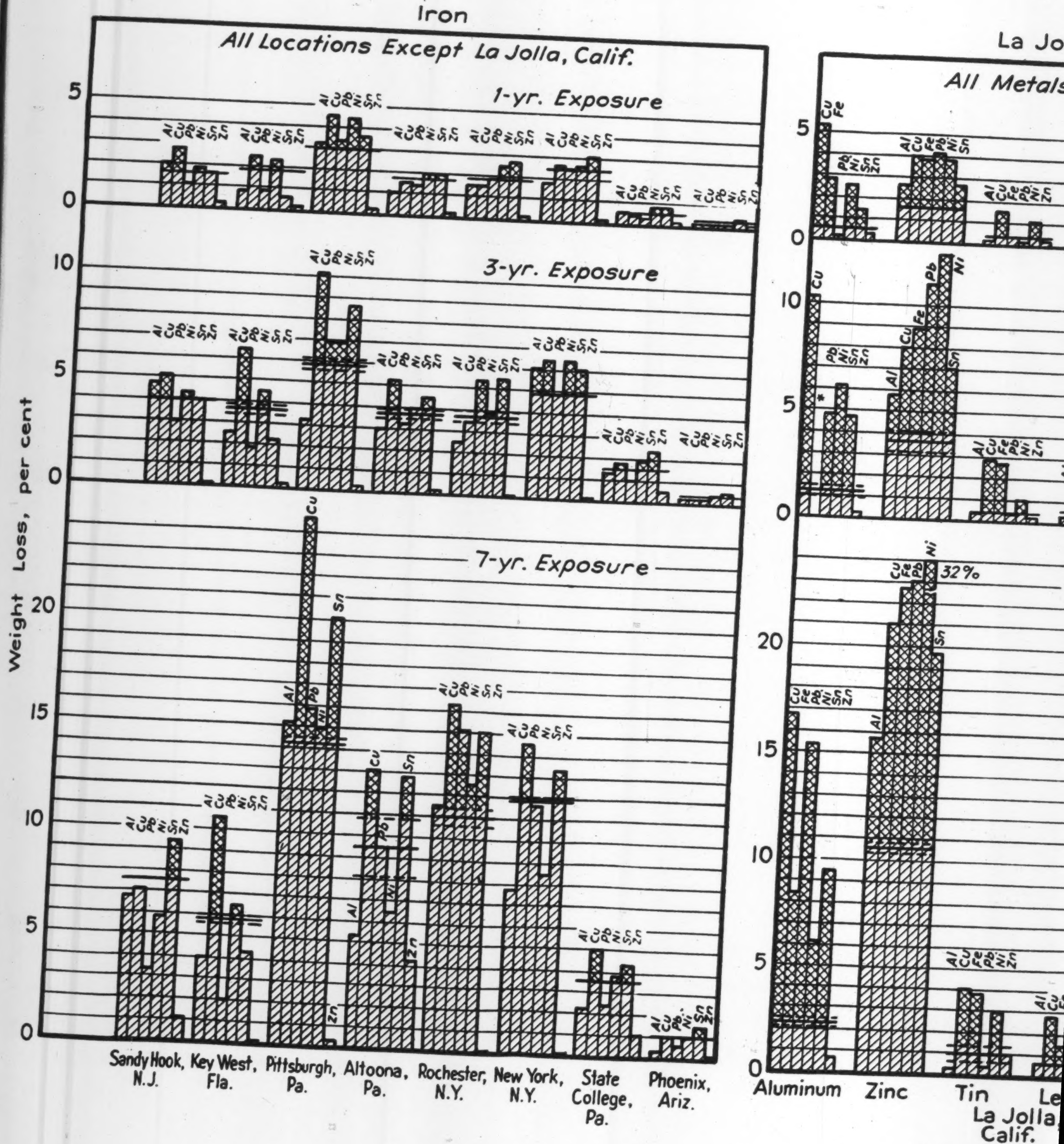
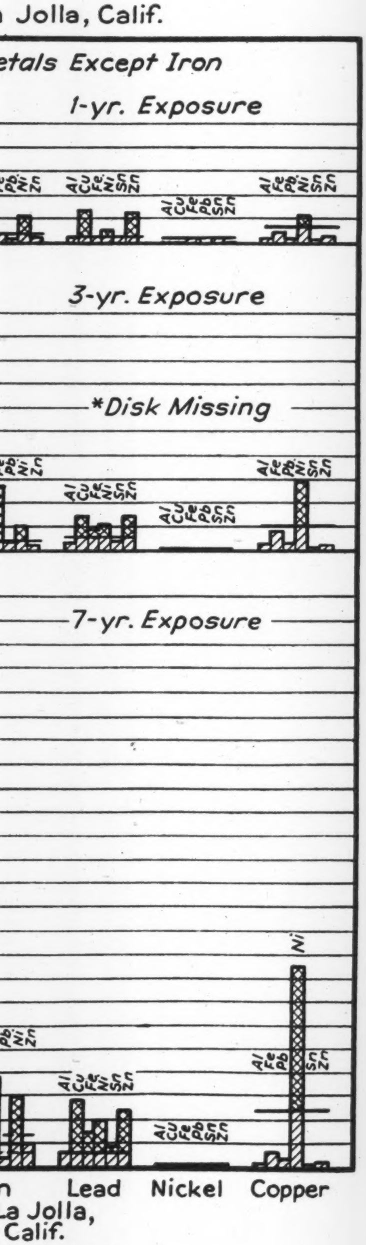


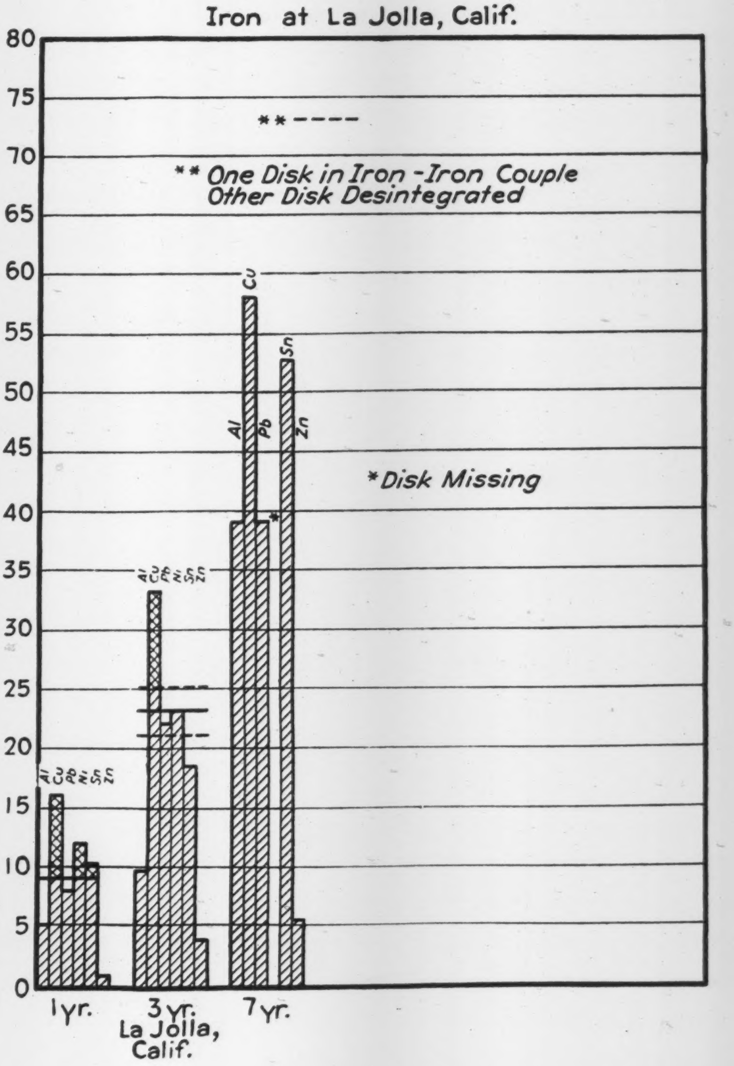
FIG. 4.—Weight Loss of D



Loss of Disks.

Nominal Weights of Disks

Aluminum	4.6 g.	Nickel	14.6 g.
Copper	14.9 g.	Tin	12.4 g.
Iron	12.8 g.	Zinc	11.9 g.
Lead	19.1 g.		



coupled with the metals indicated by the chemical symbols. For example, the group marked aluminum shows the percentage losses in weight of the aluminum disks when coupled with copper, iron, lead, nickel, tin, and zinc, respectively.

The solid line through a group shows the average weight loss of the two disks of the same metal coupled together as a blank and represents the normal corrosion of the metal in this form of specimen. Dotted lines are used to show the loss of weight for the individual disks in the blanks. Where the difference is less than 0.1 per cent the dotted lines have been omitted. The double cross-hatching is used to indicate cases where the corrosion was greater than the weight loss of the highest blank and represents accelerated corrosion of the metal concerned by the other metal in the couple. Similarly, retarded corrosion is indicated by the columns which fall below the lowest blank.

Discussion:

The committee feels that it is inadvisable to make any generalized statements regarding the behavior of the couples. Such generalizations would, of necessity, require the adoption of some arbitrary standard of corrosion which probably would not apply equally to all the metals under their various conditions of use. It is felt that the cases where acceleration or protection is definite are obvious from a careful study of the data in the tables and charts. It is thus possible in such cases for an individual to interpret the data for his particular needs. For this reason, it has been decided to discuss individually only those couples whose behavior seems to be unusual. Before doing this, however, it may be well to discuss the limitations of the tests and some of the precautions to be observed in interpreting the data.

The first important limitation to be considered is that caused by spreading of the couple during the test due to the formation of bulky corrosion products on the inner faces. This means that couple action is frequently modified by atmospheric corrosion, the effect being particularly marked in the severe locations such as La Jolla. A second complicating factor which depends in a large measure on the condition just described is that of contact resistance between the two members of the couples. In some cases resistances became high enough to limit couple action soon after the start of the test and the number of cases where couple action was limited in this way probably increased as the tests progressed. Another unforeseen variable is that caused by imperfect adhesion of the paints used to protect the outer surfaces of the disk. Where adhesion was poor, atmospheric corrosion took place on the outer surface of the disks, thus complicating the evaluations of the extent of couple action.

It is felt that the data in Table VI (Plate IV) adequately summarizes the results of the tests. The data in this table represent the percentage weight loss of each disk when coupled with itself and when coupled with each of the other metals. In view of the restricted conditions of the test the rates of corrosion of the disks should not be used to calculate their life expectancies. The figures are of a relative nature and serve their best use when they are compared with other figures in the table. A comparison of the percentage weight loss of a disk when coupled with itself and when coupled with another metal will indicate the extent of the protection or acceleration due to the couple action.

Thus, at La Jolla, aluminum coupled with aluminum lost 2.3 per cent of its weight after 7 yr., whereas aluminum coupled with copper lost 16.6 per cent. This is a definite indication of couple action. Also, the copper disk coupled with aluminum was definitely protected by the couple action since by itself it lost 2.4 per cent, whereas when coupled with aluminum it lost only 0.2 per cent. In evaluating the extent and significance of couple action, it is important to consider the effect on both disks constituting the couple. When one disk is protected at the expense of its mate, couple action is undoubtedly significant. Where both members of the couple are either protected or accelerated, it may be suspected that couple action has been influenced by other factors.

In many cases, the effect of couple action is not as apparent as in the example given above, and it may be difficult to decide whether to attach any significance to the figures. In such cases it is helpful to study the figures for the 1 and 3-yr. periods together with the 7-yr. period, and to observe also the behavior of these couples at other locations, particularly where the atmospheric conditions are similar. This study of the corrosion trend for the three periods will also help to detect the inconsistencies in the data due to experimental errors or to the unforeseen changes in conditions which were considered earlier in this discussion.

In a number of cases, the behavior of the couples is inconsistent with the assumption that the electromotive series predicts their behavior. This assumption is not completely justified since it overlooks the effect of film formation and of environment on the magnitude and direction of galvanic action. Furthermore, it is important to recognize that this series is based upon certain prescribed test conditions which are far from the conditions to be expected in most atmospheres. For this reason a service behavior not in accord with a prediction based upon the electromotive series may frequently be expected. In fact, the data of this report furnish a number of illustrations of the fallacy of too literally applying the electromotive series. The more obvious cases of unusual behavior are discussed below.

Aluminum-Zinc.—It will be noticed that zinc which according to the electromotive series is cathodic to aluminum has protected it at every test location. This may be caused by the ennobling effect of the characteristic protective oxide film which forms on aluminum.

Aluminum-Copper.—Although copper has significantly accelerated the corrosion of aluminum at most of the test locations, the attack on the aluminum disks coupled to copper at Pittsburgh was relatively slight. It is known, however, that the potential relations between aluminum and copper in sulfate solutions differ from those which obtain in chloride solutions, and it is entirely possible that the Pittsburgh atmosphere has favored the formation of a solution acting like a sulfate solution.

Copper-Nickel.—Copper was protected by nickel in five of the nine locations. At these locations nickel apparently behaves as a normally active metal, and significantly protects the copper. The acceleration of the corrosion of copper in this couple at La Jolla can be attributed to the possibility that the air-formed passive film on nickel is not broken down by the marine atmosphere at this location and that copper is anodic to this passive film. It is also possible that the heavy crust of corrosion product about the couples at La Jolla helped to maintain an environment in which the nickel remained passive.

Tin-Nickel.—Similar behavior is observed in the case of tin-nickel at La Jolla, where corrosion of tin was definitely accelerated by contact with nickel. At Pittsburgh, tin is protected by nickel, while at the other locations couple action is relatively insignificant. The explanation of this behavior is probably the same as that given in the discussion of copper-nickel.

Copper-Iron, Lead-Iron and Tin-Iron. —In the case of these couples at La Jolla, there was an apparent protection afforded the iron, although this would not have been expected from the action of the other member of the couple. In these cases, the effect is probably not significant since the variation in the normal corrosion of iron is wide and may overshadow the true effect of couple action.

Lead-Zinc.—Corrosion of both members of this couple was accelerated to some extent in the marine atmosphere. The acceleraton of lead may possibly be due to the effect of the corrosion products which formed as a result of couple action.

Zinc-Iron.—With the exception of lead in the marine atmospheres, zinc protects all the metals at all locations. However, the acceleration of its corrosion in contact with iron was less than that anticipated from the extent of the protection afforded. It will be noticed that the zinc-iron couples in general remained tight during exposure, whereas the iron-iron couples tended to open up, permitting corrosion on the inner faces. The extent of the reduction in corrosion of the iron in contact with the zinc must have been influenced by the mechanical protection resulting from the tightness of the couples. Similar effects undoubtedly occurred in many other locations.

It will be observed that a large number of the cases of unusual behavior occurred at La Jolla. This is probably largely due to the extreme severity of the conditions at this location. The locations rating next in severity are the industrial and the other marine locations between which it is not in general possible to differentiate. Couple action at the rural locations, State College and Phoenix is definitely the least severe.

Respectfully submitted on behalf of the subcommittee,

L. J. Gorman,
Chairman.

REPORT OF COMMITTEE B-4

ON

ELECTRICAL-HEATING, ELECTRICAL-RESISTANCE AND ELECTRIC-FURNACE ALLOYS

Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys held two meetings during the year, in Washington, D. C., on October 27 and 28, 1938, and in New York City on February 16 and 17, 1939, in addition to the meeting held during the annual meeting of the Society.

The committee consists of 45 members, of whom 20 are classified as producers, 18 as consumers, and 7 as general interests.

I. New Tentative Standard

The committee recommends that the proposed Tentative Methods of Testing Nickel and Nickel-Alloy Wire and Ribbon for Electronic Tube Filaments be accepted for publication as tentative, as appended hereto.[1]

II. Revision of Tentative Standard

The committee recommends that the Tentative Method of Test for Flexivity of Thermoflex (Thermostatic Metals) (B 106 - 37 T)[2] be revised as appended hereto[1] and continued as tentative.

III. Revision of Standards

The committee recommends for immediate adoption, revisions in four standards, as indicated below, and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society.

Standard Method of Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (*B 70 - 30*):[3]

Section 1.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

> 1. This method [covers the determination of] *of test provides a procedure for determining* the change of resistance with temperature of metallic materials for electrical heating, and is applicable [at temperatures up to 500 C., or higher] *over the range of service temperatures.*

Section 2.—Change from its present form: namely,

> 2. The test specimen shall be prepared in a form suitable for measuring the temperature in an electric-resistance furnace. When the resistance measurement is to be made with a Kelvin double bridge or a potentiometer, the specimens shall be provided with four leads, either integral with or welded to the specimen. When a Kelvin double bridge is used, each lead shall have a resistance not exceeding one-fourth of the resistance of the specimen between the points of attachment of the potential leads. In any case the leads shall be in pairs and located near the ends of the specimen. The distance between the points of attachment of a potential lead and its corresponding current lead shall be less than one-tenth of the length of the specimen between the potential leads. The two outside leads shall be used for current and the two inside ones for potential. When the resistance is to

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[1] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 711 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 437.

[3] 1936 Book of A.S.T.M. Standards, Part I, p. 745.

be measured by a Wheatstone bridge, the resistance of the leads shall not exceed 1 per cent of the resistance of the specimen.

to read as follows:

2. The test specimen shall be prepared in a form suitable for measuring its resistance in an electric furnace. When the resistance is to be measured with a Kelvin bridge or a potentiometer, a current lead shall be welded to each end of the specimen in such a manner that there will be no change of current distribution in the specimen during measurements. Potential leads, one at each end, shall be attached by welding at a distance from the corresponding current lead not less than one-tenth of the length of the specimen between the potential leads.

Section 3.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

3. *When the resistance is to be measured with a Wheatstone bridge, only the current leads are required. The resistance of the leads in this case shall not exceed 1 per cent of the resistance of the specimen, and* the leads shall be *made* of the same [material] *type of alloy* as [that of] the test specimen. [They] *For both methods of measurement, the leads* shall have a length within the heated zone of the furnace of at least 50 times their minimum transverse dimension, in order to avoid disturbance of the temperature of the specimen by conduction of heat to the colder parts of the furnace.

Section 5.—Add the following as the first two sentences of this section:

A Kelvin bridge or a potentiometer shall be used when measuring specimens of less than 10-ohm resistance. A Wheatstone bridge may be used with specimens of resistance greater than 10 ohms.

Change the present first sentence of this section to read as follows by the addition of the italicized words:

The resistance *of the specimen* shall be measured with an accuracy of 0.1 per cent.

Standard Accelerated Life Test for Metallic Materials for Electrical Heating (B 76 – 38):[4]

The changes given below are proposed in order to provide a method for determining the increase in length of the test specimen during the life test, or the change in length between room temperature and operating temperature.

Section 3.—Add a new Paragraph (*i*) to this section to read as follows:

(*i*) *Apparatus for Measuring Length Changes.*—Any form of optical apparatus such as a traveling microscope, an optical projection system, a projection microscope, or a contact microscope may be used for determining changes in length of the test specimen. A type of apparatus that has been found satisfactory consists of a telescope with a horizontal cross hair and leveling bubble. The apparatus may be mounted on a frame so that it can be readily moved from one position to another for examining specimens in the life test. The telescope mount should be adjustable in the vertical plane on guides by means of a threaded member. A movement of 2.5 in. is desirable. A piece of cross-section paper, 4 in. in length by 3 in. in width, calibrated 20 lines to the inch, should be mounted on the test panel so that the lower edge is below a horizontal line drawn across the top of the lowest possible position of the weight attached to the lower end of the wire under test. A satisfactory arrangement is shown in Fig. 5 (the accompanying Fig. 1). A steel scale 18 in. in length, calibrated to 0.01 in. may be used for length measurements.

Section 8.—Add a new Paragraph (*n*) to this section to read as follows:

(*n*) *Length Changes of Specimen.*—Changes in length of the test specimen may be determined with an accuracy of 0.5 per cent by the following procedure: First measure with a steel scale the length between the point at which the specimen wire leaves the upper binding post and the top of the weight attached to the lower end of the specimen wire. This measurement should be accurate to plus or minus 0.01 in. Adjust the telescope in the vertical plane until the cross hair is directly lined up with the top of the weight attached to the wire. Make a reading on the cross-section paper attached to the panel at the point where the cross hair intercepts the wire, after the first period adjustment (see Paragraph (*h*)). Estimate the readings on the cross-section paper to the nearest 0.01 in. Other readings through the telescope may be taken in the same manner and noted. Calculate the changes in length of the specimen as the difference between the first reading made on the cross-section paper and the subsequent readings.

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[4] 1938 Supplement to Book of A.S.T.M. Standards, p. 75.

Section 10.—Add a new Paragraph (*g*) to this section to read as follows:

> (*g*) *Length Changes of Specimen.*—The changes in length of the specimen during the course of the life test, when reported, shall be given as the percentage change in length per 100 hr. of elapsed time, starting with the time at which the first measurement is made.

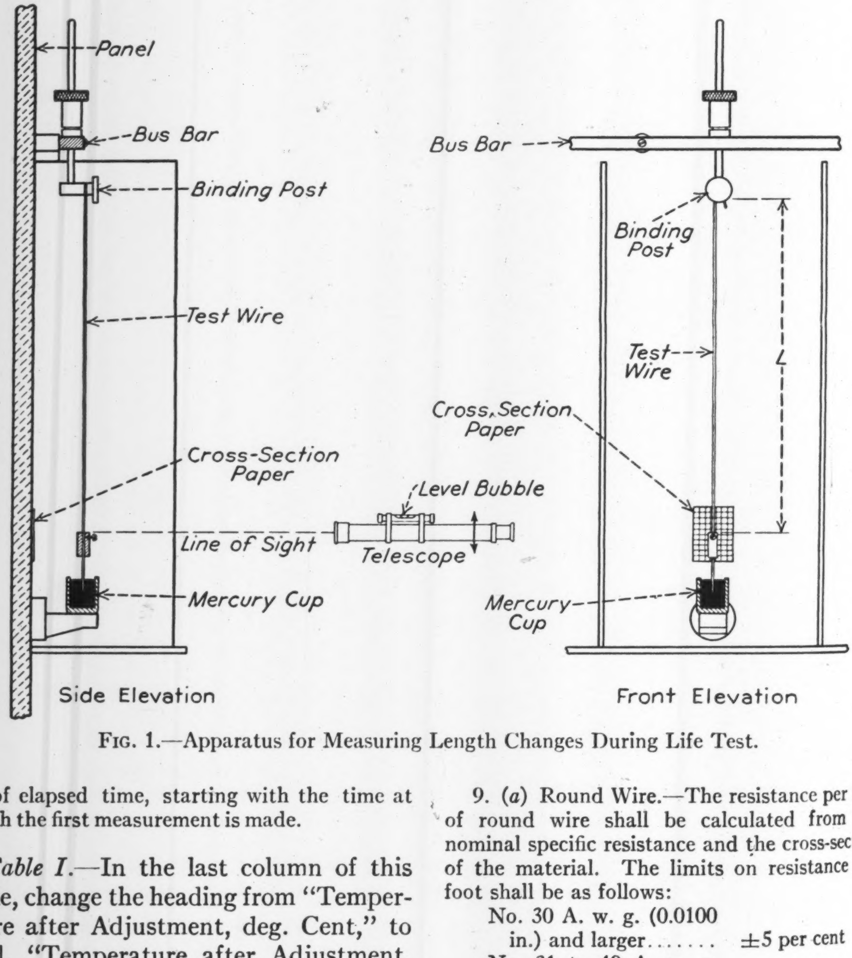
Panel
Bus Bar
Binding Post
Test Wire
Cross-Section Paper
Level Bubble
Line of Sight
Telescope
Mercury Cup
Side Elevation
Bus Bar
Binding Post
Test Wire
L
Cross-Section Paper
Mercury Cup
Front Elevation

FIG. 1.—Apparatus for Measuring Length Changes During Life Test.

Table I.—In the last column of this table, change the heading from "Temperature after Adjustment, deg. Cent," to read, "Temperature after Adjustment, deg. Fahr."

Standard Specifications for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical Heating Elements (B 82 – 34):[5]

Section 3.—In the table of chemical composition requirements change the percentage of silicon from "0.40 max." to read "0.75 to 1.50;" also change the maximum percentage of iron from "1.5" to read "1.0."

Section 9 (*a*).—Change from its present form: namely,

> 9. (*a*) Round Wire.—The resistance per foot of round wire shall be calculated from the nominal specific resistance and the cross-section of the material. The limits on resistance per foot shall be as follows:

No. 30 A. w. g. (0.0100 in.) and larger.......	±5 per cent
No. 31 to 40 A. w. g. (0.0089 to 0.0031 in.)...	±8 per cent
No. 40 A. w. g. (0.0031 in.) and smaller.....	±10 per cent

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[5] 1936 Book of A.S.T.M. Standards, Part I, p. 726.

to read as follows:

9. (*a*) ***Round Wire***.—The nominal resistance per foot of round wire shall be calculated from the nominal specific resistance and the cross-section of the material. The actual resistance per foot shall not vary from the nominal resistance per foot more than the following amounts:

No. 40 A.w.g. (0.0031 in.) and larger	± 5 per cent
Smaller than No. 40 A.w.g. (0.0031 in.)	± 8 per cent

(*b*) *Strip.*—The nominal resistance per foot of strip shall be calculated from the nominal specific resistance and the cross-section of the material. In order to compensate for error in the calculated cross-section on ribbon with rounded edges, the calculated values arrived at by multiplying the nominal width by nominal thickness shall be corrected by multiplying by the factor indicated in the following table:

Ratio of Width to Thickness	Factor
15 and under	0.94
Over 15	0.83

The actual resistance per foot shall not vary from the nominal resistance per foot more than the following amounts:

Hot-rolled flats	± 8 per cent
Cold-finished strip	± 5 per cent

Section 10.—Change from its present form: namely,

10. Temperature coefficient of resistance shall, after the wire has been slowly cooled from an annealing temperature, be measured in accordance with the Standard Method of Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (A.S.T.M. Designation: B 70) of the American Society for Testing Materials. The temperature coefficient of resistance shall be such as will bring the resistance within ±20 per cent of the following:

Temperature	Resistance, per cent
77 F. (25 C.)	100.0
800 F. (427 C.)	103.7
1000 F. (539 C.)	104.0
1200 F. (649 C.)	103.3
1400 F. (760 C.)	103.2
1600 F. (871 C.)	103.6
1800 F. (980 C.)	104.1
2000 F. (1094 C.)	104.8

to read as follows, renumbering the remaining sections accordingly:

10. The temperature coefficient of resistance shall be such as will bring the resistance change within plus or minus 20 per cent of the change indicated in the following table:

Temperature	Resistance, per cent
20 C. (68 F.)	100.0
200 C. (392 F.)	101.3
300 C. (572 F.)	102.1
400 C. (752 F.)	102.8
500 C. (932 F.)	103.3
600 C. (1112 F.)	102.8
800 C. (1472 F.)	102.1
1000 C. (1832 F.)	103.3

11. After the material has been slowly cooled from an annealing temperature, the temperature coefficient of resistance shall be measured in accordance with the Standard Method of Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (A.S.T.M. Designation: B 70) of the American Society for Testing Materials.

Section 13.—Renumber as Section 14 and in Paragraph (*a*) change the diameter of flange used in spooling wire of 1 lb. from "2 in." to read "2$\frac{1}{2}$ in."

Standard Specifications for Drawn or Rolled Alloy, 60 per cent Nickel, 15 per cent Chromium, and Balance Iron, for Electrical Heating Elements (B 83–34):[6]

Section 3.—In the table of chemical composition requirements change the percentage of silicon from "0.40 max." to read "0.75 to 1.50."

Sections 9 and 13.—Make the same changes in these sections as are recommended above in Specifications B 82.

Section 10.—Change from its present form which is identical with Section 10 of Standard B 82 as given above, to read as follows:

10. The temperature coefficient of resistance shall be such as will bring the resistance change within plus or minus 20 per cent of the change indicated in the following table:

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[6] 1936 Book of A.S.T.M. Standards, Part I, p. 730.

Temperature	Resistance, per cent
77 F. (25 C.)	100.0
800 F. (427 C.)	109.2
1000 F. (539 C.)	110.7
1200 F. (649 C.)	111.2
1400 F. (760 C.)	111.9
1600 F. (871 C.)	113.0

11. After the material has been slowly cooled from an annealing temperature, the temperature coefficient of resistance shall be measured in accordance with the Standard Method of Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (A.S.T.M. Designation: B 70) of the American Society for Testing Materials.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. New Tentative Standard			
Methods of Testing Nickel and Nickel-Alloy Wire and Ribbon for Electronic Tube Filaments	32	0	10
II. Revision of Tentative Standard			
Test for Flexivity of Thermoflex (Thermostatic Metals) (B 106 - 37 T)	31	0	13
III. Revision of Standards			
Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (B 70 - 30), immediate adoption	35	0	7
Accelerated Life Test for Metallic Materials for Electrical Heating (B 76 - 38), immediate adoption	35	0	7
Specifications for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical Heating Elements (B 82 - 34), immediate adoption	33	0	9
Specifications for Drawn or Rolled Alloy, 60 per cent Nickel, 15 per cent Chromium, and Balance Iron, for Electrical Heating Elements (B 83 - 34), immediate adoption	33	0	9
IV. Adoption of Tentative Standards as Standard			
Test for Temperature-Resistance Constants of Sheet Materials for Shunts and Precision Resistors (B 114 - 38 T)	32	0	10
Test for Linear Expansion of Metals (B 95 - 35 T), as revised	32	0	10

IV. Adoption of Tentative Standards as Standard

The committee recommends that the following two tentative methods, with revisions in one, be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of:

Test for Temperature-Resistance Constants of Sheet Materials for Shunts and Precision Resistors (B 114 - 38 T),[7]

Test for Linear Expansion of Metals (B 95 - 35 T),[8] revised as appended hereto.[1]

V. Standards Continued Without Revision

The committee has reviewed the following standards under its jurisdiction, one of which has been standing six years without revision, and has made certain improvements and changes of an editorial nature:

Standard Methods of:

Test for Resistivity of Metallic Materials (B 63 - 36),

Test for Thermoelectric Power of Electrical-Resistance Alloys (B 77 - 33), and

Test for Temperature-Resistance Constants of Alloy Wires for Precision Resistors (B 84 - 36).

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 45 members; 42 members returned their ballots, the results being shown in Table I.

Activities of Subcommittees

Subcommittee I on Life Tests (J. W. Harsch, chairman).—An addition has been made to the Accelerated Life Test (B 76 - 38), as mentioned earlier in this report, to provide a method of determining the increase in length of the test specimen during the life test, or the change in length between room temperature and operating temperature.

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[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 724 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 454.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 755 (1935); also 1938 Book of A.S.T.M. Tentative Standards, p. 443.

The effect of the humidity of the atmosphere upon the life of electric heater wires is being investigated. This apparently is a factor in the seasonal variation which has been noted in the life test results. A study is also being made of the effect of ceramics and cements upon the life of heating element materials in contact with them.

Subcommittee II on Electrical Tests (P. H. Dike, chairman).—The four standard methods and one tentative method under the jurisdiction of this subcommittee have been reviewed and a number of editorial changes have been made, with some minor changes of substance in the Test for Change of Resistance with Temperature (B 70 – 30).

The question of undertaking the preparation of methods of test for some types of electrical contact materials is under consideration.

Subcommittee IV on Mechanical Tests (P. H. Brace, chairman).—A study of the Tentative Method for Bend Testing of Wire (B 113 – 38 T), in connection with other bend test methods described in the 1936 report[9] of the committee, is being made to determine whether constant proportionality factors can be developed. Specimens of nine different tempers of nickel-chromium, nickel, iron, copper, and monel metal have been tested and the data are being analyzed. Tension tests also have been made. It is planned to extend the bend test to include strip as well as wire.

The resilience test for strip (determined by the amount of spring back when flexed) is being investigated.

Subcommittee V on Wrought and Cast Alloys for High-Temperature Use (C. L. Clark, chairman).—Bend tests on cast bars for electric-furnace structures have been made at 1800 F. with the bend test equipment built by the Union Carbide and Carbon Research Laboratories in cooperation with this subcommittee, and the data are being studied together with the shape of the specimen and the method of loading.

Several shapes and sizes of specimens have been investigated to provide a warpage test to determine the tendency of materials to warp when subjected to wide variations in temperature. It is very difficult to prepare a test procedure that will indicate the relative tendency of various materials to warp under service conditions.

Subcommittee VI on Specifications (J. W. Harsch, chairman).—As indicated earlier in this report, the Standard Specifications for Alloys for Electrical Heating Elements (B 82 – 34 and B 83 – 34) have been brought up to date in accordance with present practice.

Subcommittee VII on Thermostatic Metals (P. H. Brace, chairman).—The Tentative Method of Test for Flexivity of Thermoflex (Thermostatic Metals) (B 106 – 37 T) has been revised in minor details and is continued as tentative. Work is being continued on the development of a method for determining the effective modulus and permissible operating stresses of thermostatic metals. A study has been made of the effect of shearing in distorting the edges of thermostatic metals, means for removing such distortion, and the beneficial effect of such removal.

Subcommittee VIII on Metallic Materials for Radio Tubes and Incandescent Lamps (A. L. Chapman, chairman).—A proposed Method of Testing Nickel and Nickel-Alloy Ribbon and Wire for Electronic Filaments has been prepared and is being submitted for publication as tentative. It is expected that the Proposed Method of Testing Cathode

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[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 162 (1936).

Sleeves and Cathode Tubing, which was published as information with the report of the committee last year,[10] will be submitted shortly for publication as tentative.

Samples of good tungsten wire and of brittle wire are being distributed to several laboratories for test to develop the best method of determining brittleness.

Other subjects under consideration by this subcommittee include a method of determining the thickness of nickel plating on steel strip, a test for temper of nickel-plated steel strip, and a test for copper-coated sealing-in wire for lamps and radio tubes.

Subcommittee IX on Effect of Furnace Atmospheres on Furnace Resistors (P. H. Brace, chairman).—Previous work of the subcommittee indicated that the nodular type of resistor failure was connected with the presence of sulfur. A standard atmosphere was used for these tests. Another type of attack occasionally was encountered in the field wherein deterioration tended to occur throughout the cross-section of the material and was believed due to certain critical atmospheres.

During the past year, it has been found that cyclic variations of furnace atmosphere may be more destructive than any one composition within the range of variation. This phenomenon has been studied by three laboratories during the year. The results indicate that the mechanism of deterioration of resistors in controlled atmospheres is even more complicated than had been realized, and that further work is necessary before a standard method of test can be decided upon.

This report has been submitted to letter ballot of the committee which consists of 45 members; 42 members have returned their ballots, of whom 40 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

DEAN HARVEY,
Chairman.

F. E. BASH,
Secretary.

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[10] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 220 (1938).

REPORT OF COMMITTEE B-5

ON

COPPER AND COPPER ALLOYS, CAST AND WROUGHT

Committee B-5 on Copper and Copper Alloys held two meetings during the year: in Atlantic City, N. J., on June 30, 1938, and in Columbus, Ohio, on March 10, 1939, with an attendance at the two meetings of the committee and its subcommittees of 41 and 39, respectively.

At the present time the committee consists of 74 members, of whom 69 are voting members; 27 are classified as producers, 25 as consumers, and 17 as general interest members.

Subsequent to the 1938 annual meeting, Committee B-5 presented to the Society through Committee E-10 on Standards a revision of the Tentative Specifications for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 37 T) and a tentative revision of the Standard Specifications for Aluminum-Bronze Castings (B 59 - 38). These recommendations were accepted[1] by Committee E-10 on August 25, 1938, and appear in the 1938 *Proceedings*.[2]

I. New Tentative Standards

The committee recommends that the following six new tentative standards[3] be accepted for publication:

Tentative Specifications for:

- Leaded Brass Sheet and Strip,
- Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip,
- Beryllium-Copper Alloy Bars, Rods, Sheet, Strip, and Wire,
- Copper-Base Alloy Forging Rods, Bars, and Shapes to replace immediately the Standard Specifications for Brass Forging Rod (B 15 - 18),
- Leaded-Nickel-Brass and Leaded-Nickel-Bronze (Nickel-Silver) Alloys in Ingot Form for Sand Castings, and

Tentative Classification of Cast Copper-Base Alloys.

II. Revisions of Tentative Standards

The committee recommends revisions of the following two tentative specifications, as given in detail below:

Tentative Specifications for Sheet and Strip Phosphor Bronze (B 103 - 36 T):[4]

Section 2 (*a*).—Change from its present form to read as follows:

2. (*a*) The phosphor bronze shall be made from materials conforming to the requirements of the following specifications of the American Society for Testing Materials:

Copper.—Standard Specifications for Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (A.S.T.M. Designation: B 4), or Standard Specifications for Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (A.S.T.M. Designation: B 5).

Phosphor Copper.—Tentative Specifications for Phosphor Copper (A.S.T.M. Designation: B 52).

Phosphor Tin.—Tentative Specifications for Phosphor Tin (A.S.T.M. Designation: B 51).

Pig Lead (*Common Lead*).—Standard Specifications for Pig Lead (A.S.T.M. Designation: B 29).

Tin.—Equal to "Banca" or "Straits."

Clean, new scrap resulting from manufacturing operations upon material complying with these specifications or composed of material of equal purity may be used.

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[1] In submitting these recommendations to Committee E-10 on Standards, Committee B-5 reported the following results of the letter ballot vote of a total of 44 ballots returned from a committee membership of 70: B 111 - 38 T, Affirmative 32, negative 0, ballots marked "not voting" 12; B 59 - 38, affirmative 28, negative 0, ballots marked "not voting" 15.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 702, 1319 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 379, 1685.

[3] These specifications and the classification were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 734 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 372.

Section 3.—In the table of chemical composition add the following requirements for grade B phosphor bronze:

GRADE B

Copper, per cent	remainder
Tin, per cent	4.00 to 5.50
Phosphorus, per cent	0.03 to 0.25
Iron, max., per cent	0.10
Lead, per cent	2.50 to 4.00
Zinc, max., per cent	0.20
Nickel, max., per cent	....
Copper plus tin plus lead plus phosphorus, min., per cent	99.50

Table I.—Change the title of the table to include grade "B" phosphor bronze sheet, and change the title of the first section of the table from "Grade A Phosphor Bronze Sheet" to read "Grades A and B Phosphor Bronze Sheet."

TABLE I.—TOLERANCES IN WIDTH, PLUS AND MINUS, IN.

SLIT METAL

Width, in.	Gage, in.	
	0.004 to 0.032, incl.	Over 0.032 to 0.182, incl.
Up to 2, incl.	0.005	0.010
Over 2 to 8, incl.	0.008	0.013
Over 8 to 14, incl.	0.010	0.015
Over 14 to 20, incl.	0.013	0.018

SQUARE SHEARED

Width, in.	Gage, in.	
	Up to 0.125, incl.	Over 0.125
Up to 60, incl.	1/32	1/16

Section 12.—Change the permissible variations in dimensions from their present form to read as follows:

12. *Width.*—The width of phosphor bronze sheet and strip shall be within the permissible variations prescribed in Table III (the accompanying Table I). All permissible variations in width are plus and minus. When permissible variations in width are specified all plus or all minus, the variations shown in Table III shall be doubled.

Table II.—Expand this table to include the following permissible variations in thickness for material over 20 in. in width:

TOLERANCES IN THICKNESS, PLUS AND MINUS, IN.

Thickness, in.	Over 20 to 28 in. in Width, incl.	Over 28 to 36 in. in Width, incl.	Over 36 to 48 in. in Width, incl.	Over 48 to 60 in. in Width, incl.	Over 60 in.
Over 0.020 to 0.025	0.0030	0.0034	0.0039	0.0043	......
Over 0.025 to 0.050	0.0039	0.0046	0.0055	0.0063	0.0071
Over 0.050 to 0.100	0.0050	0.0064	0.0080	0.010	0.011
Over 0.100 to 0.200	0.0069	0.0094	0.012	0.015	0.019
Over 0.200 to 0.500	0.0096	0.013	0.017	0.021	0.026
Over 0.500 to 1.00	0.015	0.020	0.026	0.034	0.043
Over 1.00 to 2.00	0.028	0.036	0.046	0.058	0.069

Tentative Specifications for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 38 T):[5]

Section 4.—Change footnote *b* referring to Muntz metal, admiralty, and aluminum brass to read as follows by the addition of the italicized words and the omission of those in brackets:

> [b] If agreed upon between the manufacturer and the purchaser, these alloys may contain a maximum of [0.25] *0.15* per cent antimony, [or maximum of] 0.1*0* per cent arsenic, *or 0.20 per cent phosphorus.*

III. REVISIONS OF STANDARDS

The committee recommends for immediate adoption, the following revision of the Standard Specifications for Copper Water Tube (B 88 - 33; A.S.A. H 23.1 - 1934),[6] and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that this modification may be referred to letter ballot of the Society:

Section 7.—Change Paragraphs (*a*) and (*b*), and Table I from their present form: namely,

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[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 702 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 379.

[6] 1936 Book of A.S.T.M. Standards, Part I, pp. 626 563, 565.

7. (*a*) Specimens of full cross-section and suitable length shall show the requirements as to tensile properties shown in Table I.

(*b*) A microscopic examination of specimens from tubes selected for purpose of tests shall show complete recrystallization with uniform grain sizes as shown in Table I.

TABLE I.—TENSILE STRENGTH AND GRAIN SIZE REQUIREMENTS.

	Nominal Temper		
	Annealed	Light Temper[a]	Hard Drawn
Tensile strength, psi. min.	30 000	32 000	48 000
max.	......	40 000	......
Elongation in 4 in., min., per cent	25	......	......
Mean grain size, mm	0.025 to 0.075	......	......

[a] This temper may be obtained either by a light draft or light anneal.

to read as follows:

7. (*a*) Specimens of suitable length shall show the requirements as to tensile properties shown in Table I (the accompanying Table II), and shall be tested in accordance with the Standard Methods of Tension Testing of Metallic Materials (A.S.T.M. Designation: E 8) of the American Society for Testing Materials.

TABLE II.—TENSILE STRENGTH AND GRAIN SIZE REQUIREMENTS.

	Annealed, All Sizes	Light Temper, ⅜ to 1¼ in., incl.	Drawn Temper, All Sizes
Tensile strength, psi. min.	30 000	40 000	40 000
Tensile strength, psi. max.	......	50 000	......
Elongation in 4 in. min., per cent	25	......	......
Average grain size, min., mm	0.040	......	......

(*b*) The test specimen for the microscopic examination shall be a radial longitudinal section of the tube made by cutting along a plane containing the longitudinal axis of the tube.

Sections 8 to 11.—Omit these sections and add a new Section 8 to read as follows, renumbering the subsequent sections accordingly:

8. The annealed material shall be capable of being expanded on a hardened and ground, tapered steel pin having an included angle of 60 deg., to the following amount:

Nominal Size, Outside Diameter, in.	Expansion of Outside Diameter, per cent
Up to ¾, incl.	40
Over ¾	30

The committee recommends that the revisions proposed in the following two standard specifications be accepted for publication as tentative:

Standard Specifications for Manganese-Bronze Ingots for Sand Castings (B 7 – 27):[6]

Section 1.—Change to read as follows by the addition of the italicized words and the omission of the word in brackets:

1. These specifications cover [the] *two* copper-zinc alloys, *grades A and B,* known commercially as manganese bronze. *Grade B is known as high-strength manganese bronze.*

Section 3.—Designate the present chemical composition requirements as covering grade A, and add the following requirements for grade B:

	Grade B	
	Maximum	Minimum
Copper, per cent	65.00	56.00
Zinc, per cent	remainder	remainder
Tin, per cent	1.00	...
Manganese, per cent	6.00	2.00
Aluminum, per cent	7.00	2.00
Iron, per cent	5.00	2.00
Lead, per cent	0.20	...
Nickel, per cent	3.00	...

Section 4.—Designate the present requirements for tensile properties as covering grade A, and add the following minimum requirements for grade B:

	GRADE B
Tensile strength, min., psi.	105 000
Elongation in 2 in., min., per cent	12

Standard Specifications for Manganese-Bronze Sand Castings (B 54 – 27):[6]

Sections 1 and 3.—Make the same changes in these sections as are recommended above in Specifications B 7.

Section 4.—Designate the present requirements for tensile properties as covering grade A, and add the following minimum requirements for grade B:

	GRADE B
Tensile strength, min., psi.	100 000
Elongation in 2 in., min. per cent	10

IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following three tentative specifications be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Specifications for:

Sheet Copper-Silicon Alloy (B 97 - 36 T),[7]
Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 - 36 T),[7] and
Copper-Silicon Alloy Wire for General Purposes (B 99 - 37 T).[8]

V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

The committee recommends that the tentative revisions[9] published in 1936 of the Standard Specifications for Manganese-Bronze Ingots for Sand Castings (B 7 - 27),[10] and for Manganese-Bronze Sand Castings (B 54 - 27)[10] be approved for reference to letter ballot of the Society for incorporation in the standard specifications.

It is also recommended that the tentative revision[9] accepted in August, 1938, of the Standard Specifications for Aluminum-Bronze Castings (B 59 - 38)[11] be approved for reference to letter ballot of the Society for incorporation in the standard specifications; the committee accordingly asks for the necessary nine-tenths vote at the annual meeting in order that this revision may be adopted.

VI. REVERSION OF STANDARDS TO TENTATIVE

The committee recommends that the following three standard specifications[12] be reverted to tentative and revised:[13]

Standard Specifications for:

Copper Pipe, Standard Sizes (B 42 - 33),
Seamless Copper Tubing, Bright Annealed (B 68 - 33), and
Brass Pipe, Standard Sizes (B 43 - 33).

VII. WITHDRAWAL OF STANDARD

The committee recommends the withdrawal of the Standard Specifications for Brass Forging Rod (B 15 - 18; A.S.A. H 7 - 1925),[14] to be replaced by the new Tentative Specifications for Copper-Base-Alloy Forging Rods, Bars, and Shapes.[3]

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 69 voting members, with the results shown in Table III.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Copper-Zinc Sheet and Strip (G. H. Harnden, chairman) is actively working on the Tentative Specifications for Brass Sheet and Strip (B 36 - 38 T) and expects to submit a revision of these specifications at the meeting of the committee to be held during this annual meeting.

A survey instituted by the Ordnance Department late last fall to determine their need for specifications for cartridge brass and cartridge brass disks has not as yet been completed. Therefore, no progress can be reported at this time with respect to the existing standard specifications (B 19 - 29 and B 20 - 29) covering these materials.

New Specifications for Leaded Brass Sheet and Strip have been drafted within the past year and are being recommended for publication as tentative.

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[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, pp. 751, 747 (1936); also 1938 Book of A.S.T.M. Tentative Standards, pp. 391, 387.

[8] *Proceedings*, Am. Soc Testing Mats., Vol. 37, Part I, p. 689 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 396.

[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1320, 1319 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1686, 1685.

[10] 1936 Book of A.S.T.M. Standards, Part I, pp. 563, 565.

[11] 1938 Supplement to Book of A.S.T.M. Standards, p. 84.

[12] 1936 Book of A.S.T.M. Standards, Part I, pp. 597, 635, 601.

[13] These specifications, as revised, were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

[14] 1936 Book of A.S.T.M. Standards, Part I, p. 608.

Subcommittee II on Copper-Tin Sheet and Strip (R. J. Wheeler, chairman) has recommended a revision of the Tentative Specifications for Sheet and Strip Phosphor Bronze (B 103 - 36 T) to include requirements for grade B, a leaded phosphor bronze, and to include permissible variations in thickness for sheets over 20 in. in width.

TABLE III.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Leaded Brass Sheet and Strip	42	0	15
Spec. for Copper-Nickel and Copper-Nickel-Zinc Alloy Sheet and Strip	41	0	16
Spec. for Beryllium Copper Bars, Rods, Sheet, Strip, and Wire	35	1	21
Spec. for Copper-Base-Alloy Forging Rods, Bars, and Shapes	38	0	19
Spec. for Leaded-Nickel-Brass and Leaded-Nickel-Bronze (Nickel-Silver) Alloys in Ingot Form for Sand Castings	42	1	15
Classification of Cast Copper-Base Alloys	43	2	12
II. REVISIONS OF TENTATIVE STANDARDS			
Spec. for Sheet and Strip Phosphor Bronze (B 103 - 36 T)	38	0	14
Spec. for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 38 T)	29	1	18
III. REVISIONS OF STANDARDS			
Spec. for Copper Water Tube (B 88 - 33; A.S.A. H23.1 - 1934), immediate adoption	37	0	10
Spec. for Manganese-Bronze Ingots for Sand Castings (B 7 - 27)	33	0	14
Spec. for Manganese-Bronze Sand Castings (B 54 - 27)	34	0	13
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for Sheet Copper-Silicon Alloy (B 97 - 36 T)	31	0	16
Spec. for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 - 36 T)	32	0	15
Spec. for Copper-Silicon Alloy Wire for General Purposes (B 99 - 37 T)	34	0	13
V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Spec. for Manganese-Bronze Ingots for Sand Castings (B 7 - 27)	32	0	15
Spec. for Manganese-Bronze Sand Castings (B 54 - 27)	31	0	16
Spec. for Aluminum-Bronze Castings (B 59 - 38)	31	0	16
VI. REVERSION OF STANDARDS TO TENTATIVE			
Spec. for Copper Pipe, Standard Sizes (B 42 - 33), as revised	33	0	14
Spec. for Seamless Copper Tubing, Bright Annealed (B 68 - 33), as revised	33	0	14
Spec. for Brass Pipe, Standard Sizes (B 43 - 33), as revised	35	0	17
VII. WITHDRAWAL OF STANDARD			
Spec. for Brass Forging Rod (B 15 - 18; A.S.A. H7—1925)	29	0	18

It was decided to continue as tentative for another year the Tentative Specifications for Rolled Copper-Alloy Bearing and Expansion Plates for Bridges and Other Structural Uses (B 100 - 38 T).

Subcommittee III on Copper-Nickel-Zinc Sheet and Strip (E. S. Bunn, chairman) has prepared new Specifications for Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip which are being recommended for publication as tentative. This subcommittee is also preparing specifications for leaded copper-nickel-zinc alloy sheet and strip.

Subcommittee IV on Miscellaneous Copper-Base Sheet and Strip Alloys (L. A. Ward, chairman) has prepared new Specifications for Beryllium-Copper Alloy Bars, Rods, Sheet, Strip, and Wire which are being presented for publication as tentative. This subcommittee has also recommended the adoption as standard of the Tentative Specifications for

Sheet Copper-Silicon Alloy (B 97 – 36 T). It is recommended that the Standard Specifications for Copper Plates for Locomotive Fire-boxes (B 11 – 33) be retained as standard in their present form.

It was originally intended to recommend for adoption as standard the Tentative Specifications for Copper-Silicon Alloy Plates and Sheets (B 96 – 36 T) but several changes in these specifications have been proposed by the subcommittee. It has been decided to present these revisions through Committee E-10 on Standards subsequent to the annual meeting and to continue the revised specifications as tentative.[15]

Subcommittee V on Miscellaneous Copper-Base Wire and Rod Alloys (W. H. Bassett, Jr., chairman) had hoped to present modifications of the Standard Specifications for Naval Brass Rods for Structural Purposes (B 21 – 29) covering certain changes in the physical properties. The work, however, has not been completed, and revision of these specifications is, therefore, expected to be made next year.

The Standard Specifications for Free-Cutting Brass Rod for Use in Screw Machines (B 16 – 29) are satisfactory in their present form and no changes are contemplated at the present time.

This subcommittee has recommended that the Tentative Specifications for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 – 36 T) and for Copper-Silicon Alloy Wire for General Purposes (B 99 – 37 T) be adopted as standard.

The subcommittee is also preparing new tentative specifications for copper wire and rod, copper-zinc wire and rod, copper-nickel-zinc and copper-nickel wire and rod, phosphor-bronze wire, chromium copper, special beryllium-alloy wire, and other heat-treatable copper-base alloys in the form of wire and rod.

Subcommittee VI on Condenser Tubes (G. C. HOLDER, chairman) has recommended minor changes in the Tentative Specifications for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 38 T).

A revision of the Standard Specifications for Muntz Metal Condenser Tube Plates (B 57 – 27) to include several other alloys used in the manufacture of condenser tubes is being prepared by the subcommittee. It is anticipated that this revision will be presented to the committee for consideration at its next meeting.

Subcommittee VII on Copper or Deoxidized Copper Tubes (O. Z. Klopsch, chairman) recommended that the Standard Specification for Copper Bars for Locomotive Staybolts (B 12 – 33) be discontinued since this material is no longer used in this country. In view of the use of this material in export trade, however, it was voted to retain the specifications in their present form. The subcommittee also recommended that the Standard Specifications for Seamless Copper Boiler Tubes (B 13 – 33) be discontinued as soon as the alloy covered by these specifications is included in other specifications, such as those for Seamless Copper Tubes (B 75 – 30). Recommendations were also made to revise two standard specifications which will be reverted to tentative, namely, the Standard Specifications for Copper Pipe, Standard Sizes (B 42 – 33), and for Seamless Copper Tubing, Bright Annealed (B 68 – 33). Revisions are in preparation for the Specifications for Seamless Copper Tubes (B 75 – 30). These revisions will probably be presented to the committee for consideration at its next meeting. Minor revisions are also recommended in the Standard Specifications for Copper

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[15] See Editorial Note, p. 270.

Water Tube (B 88 – 33; A.S.A. H 23.1 – 1934).

Subcommittee VIII on Copper Alloy Tubes for General Use (Alan Morris, chairman) recommended that the Standard Specifications for Brass Boiler Tubes (B 14 – 18) be withdrawn since these specifications are no longer used. It was voted, however, to postpone this withdrawal and retain the specifications in their present form, since this material is still used in export trade.

Recommendation has been made that the Standard Specifications for Brass Pipe, Standard Sizes (B 43 – 33) be rewritten and reissued as tentative. New specifications for miscellaneous brass tubes are being prepared to include those materials now covered by Standard Specifications B 14.

Subcommittee IX on Copper-Base Alloy Forgings (L. A. Ward, Chairman) has prepared new Tentative Specifications for Copper-Base-Alloy Forging Rods, Bars, and Shapes to replace the Standard Specifications for Brass Forging Rod (B 15 – 18; A.S.A. H 7 – 1925), which are recommended to be withdrawn.

Subcommittee X on Copper-Base Alloys for Sand Castings (G. H. Clamer, chairman) recommends the following changes in various specifications under its jurisdiction: (*1*) the adoption as standard of the present tentative revisions of the Standard Specifications for Manganese-Bronze Ingots for Sand Castings (B 7 – 27), and for Manganese-Bronze Sand Castings (B 54 – 27); (*2*) a tentative revision of Standard Specifications B 7 and B 54 to include requirements for a high-strength manganese-bronze alloy; (*3*) the continuance as tentative of the Tentative Specifications for Sand Castings of the Alloy: Copper 80 per cent; Tin 10 per cent; Lead 10 per cent (B 74 – 32 T); (*4*) a recommendation that new Specifications for Leaded-Nickel-Brass and Leaded-Nickel-Bronze (Nickel-Silver) Alloys in Ingot Form for Sand Castings be accepted for publication as tentative; and (*5*) the publication as a tentative standard of the Classification of Cast Copper-Base Alloys, prepared by Sam Tour. This classification has been accepted by the Non-Ferrous Ingot Metal Institute and by the American Foundrymen's Association.

The Standard Specifications for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 – 36), for Aluminum-Bronze Castings (B 59 – 38), for Castings of the Alloy: Copper 88 per cent; Tin 8 per cent; Zinc 4 per cent (B 60 – 36), for Steam or Valve Bronze Castings (B 61 – 36), and for Composition Brass or Ounce Metal Castings (B 62 – 36) were reviewed and found to be satisfactory in their present form.

Subcommittee XI on Methods of Test for Copper and Copper Alloys (A. J. Phillips, chairman) is considering the effect of anvil pressure due to different types of micrometers in measuring different thicknesses of soft metal, such as annealed brass strip and sheet as covered by the Tentative Specifications for Brass Sheet and Strip (B 36 – 38 T). It is cooperating with Committee E-1 on Methods of Testing and with various manufacturers of micrometers in order to obtain data on the correct use of micrometers. Based upon these studies, recommendations will be made to the committee with respect to the measurement of thin soft sheets. This subcommittee is also studying the tension test to determine whether or not the use of full size, unmilled tension test specimens will be satisfactory for the materials covered by the various specifications under the jurisdiction of Committee B-5.

The subcommittee is also considering the determination of the yield point as specified in the various specifications under the jurisdiction of this committee.

Subcommittee XII on Publication of General Information (C. S. Cole, chairman), in cooperation with Subcommittee X, has sponsored a paper on "Nomenclature and Classification of Cast Copper and Copper-Base Alloys," prepared by Sam Tour, which appears as an Appendix to this report. It has also sponsored a paper by E. S. Dixon on "Service and Life of Non-Ferrous Tubes in Petroleum Refining," which is being presented at this annual meeting.[16]

The subcommittee is considering the publication of a booklet of A.S.T.M. specifications pertaining to copper-base alloys. A compilation of the various terms and definitions applying to copper and the copper-alloy industry is also being prepared.

A special committee, consisting of J. R. Freeman, Jr., and J. W. Bolton, is considering the effect of temperature on the various non-ferrous alloys under the jurisdiction of this committee. Specific information is being sought on the effect of temperature on tensile strength and modulus of elasticity with particular emphasis on the maximum temperature for continuous operation of various materials, such as phosphor-bronze springs, condenser tubes, nickel-silver springs, red brass, aluminum bronze, and copper-nickel alloys.

This report has been submitted to letter ballot of the committee which consists of 69 voting members; 47 members returned their ballots, of whom 40 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. H. GREENALL,
Chairman.

C. H. DAVIS,
Secretary.

EDITORIAL NOTE

Subsequent to the annual meeting Committee B-5 presented to the Society through Committee E-10 on Standards the following recommendations:

Proposed Revision of Tentative Specifications for:

Copper-Silicon Alloy Plates and Sheets (B 96 – 36 T),
Brass Sheet and Strip (B 36 – 38 T),
Leaded Brass Sheet and Strip (B 121 – 39 T), and
Leaded-Nickel-Brass and Leaded-Nickel-Bronze (Nickel-Silver) Alloys in Ingot Form for Sand Castings (B 123 – 39 T).

These recommendations were accepted by Committee E-10 on August 24, 1939, and the revised tentative specifications appear in the 1939 Book of A.S.T.M. Standards, Part I.

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[16] ASTM BULLETIN, No. 102, January, 1940, p. 21.

APPENDIX

NOMENCLATURE AND CLASSIFICATION OF CAST COPPER AND COPPER-BASE ALLOYS

By Sam Tour[1]

Some thirty years ago, the steel industry became very active in the development of alloy steels. Out of the multitude of possible combinations of the alloying elements with iron there grew a need for a standard classification.

In response to this need, the S.A.E. numerical steel classification system was developed. The simplicity of the system appealed to everyone. It covered the field of alloys in use and permitted both producer and user to speak the same language. The system proved invaluable to the steel industry and still continues to be of value.

The S.A.E. system is a listing of chemical compositions for particular steels in classes. It has certain shortcomings as is shown by the recent need of an X designation to show differences between the two chromium-molybdenum steels 4160 and X4160.

Inherently, however, the situation in steel was not very bad. Chromium steels were called chromium steels, vanadium steels were called vanadium steels, and nickel-chromium steels were called such. In short the terminology in most cases reflected the composition of the steels. The exceptions then and the exceptions now are in the special purpose and in the tool steels.

In view of the early success of the S.A.E. system, however, and in view of the confused situation in the non-ferrous field, there developed a desire for some system of classification and identification of the many non-ferrous alloys.

A movement in this direction was started over twenty years ago. Many prominent metallurgists offered schemes. Numerical, alphabetical and combined number-letter systems were suggested. Much time was spent by many on the subject. All agreed that some system would be desirable and of great benefit but no suitable system seemed to have been thought of.

A simple numerical system such as in the S.A.E. system has been found inadequate to classify fully the one base metal iron with five different additive elements. How could a simple numerical system cover the non-ferrous field with over ten different metal bases in place of iron and with some twenty different additive elements being used with them in varying proportions? A numerical system of the decimal type can be expanded obviously to any extent needed but it becomes so extensive as to be a pure number code. Something like a library index system would be needed to decipher the code number to indicate what the number might mean. Such a system would not help to clarify the situation.

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[1] Vice President and Chemical and Metallurgical Engineer, Lucius Pitkin, Inc., New York City.

Other proposals were as indicated, combination number and letter systems. Letters as initials to designate the metals or elements and numbers to indicate the amounts present. Such systems become pure abbreviations of the chemical composition of major constituents. Due to the names of several metals beginning with the same letter of the alphabet, it is not possible to use one letter only and chemical symbols had to be resorted to. With such a system the designation of a common leaded red brass alloy would look about as follows:

$$\text{Cu} - 5\,\text{Sn} - 5\,\text{Pb} - 5\,\text{Zn}$$

and of a zinc-base die-casting alloy it would be

$$\text{Zn} - 4\,\text{Al} - 3\,\text{Cu} - 0.1\,\text{Mg}.$$

In other words, it would mean simply writing the abbreviated chemical specifications. Such systems in themselves would not standardize terminology in any class of alloys. They would not clarify the meaning of such simple words as "brass," "bronze," "white metal," let alone the host of other names and terms that have sprung up and are more or less common in the non-ferrous field.

Admitting the enormity of the job of developing some standard classification for the non-ferrous alloys does not admit the impossibility of the accomplishment.

At the start any proposed system must have some acceptance if any further progress is to be made. If the first system proposed is to cover the entire non-ferrous field, the number of different schools of thought to be satisfied are almost legion. It would, therefore, seem most logical to select a portion of the field upon which to start. The obvious field to choose was that of the copper-base alloys. This entire field, however, covers both the wrought and the cast alloys and as such involves two rather separate and distinct industries. If the attempt were confined to but one of these two industries there might be more chance of obtaining some agreement and, therefore, success.

The situation with respect to the copper alloy field was rather clearly described by the National Bureau of Standards in *Letter Circular LC 487* of January 18, 1937. With permission of the Director of that Bureau, the following is quoted from that circular:

> Many inquiries are received by the National Bureau of Standards concerning the proper use of the names "brass" and "bronze" as well as requests for advice concerning proper compositions for certain specific uses. This Letter Circular has been prepared as an aid in replying to such inquiries. Brass and bronze have been companion materials since time immemorial. The first bronze was essentially an alloy of copper with tin, whereas brass was an alloy of copper with zinc, but it was soon found that the addition of other metals to the simple binary copper-tin alloy often resulted in a material with improved properties, such as strength and corrosion resistance or more pleasing appearance. Consequently, many of our nominal copper-tin alloys contain both tin and zinc and sometimes other metals. In such alloys it is often *difficult* to determine whether the *zinc* or the *tin* has a *predominating effect;* the decision cannot be based on the numerical percentages of the two since a given amount of *tin* usually has *more effect than an equal percentage of zinc.* With increasing complexity in the composition of the alloys, it becomes increasingly difficult to determine whether a given alloy should be called a brass or a bronze. In those cases where a distinction between brass and bronze could be made, there has been no great misuse of the term "brass," save that in railroad engineering parlance any kind of a bearing is often called a "brass," referring to the bearing rather than to the alloy of which it is made. On the other hand, misapplications of the term "bronze" are frequently encountered. Bronze has long been generally accepted as being superior in a number of ways to brass and advantage

of this fact was taken in applying the term "bronze" to newly developed alloys. The term "bronze" has been applied to so many copper alloys that the simple alloys of copper with tin are now often referred to as "tin bronze."

Some of the commercially important alloys are discussed briefly in the following paragraphs:

Brass.—An alloy consisting essentially of copper (50 to 95 per cent) and zinc (50 to 5 per cent). If the *zinc* content is *greater* than *30 per cent* the alloy is a "*high brass*" or a "*yellow brass*," whereas if the *zinc* content is *less* than *20 per cent* the alloy is a "*low brass*." Brass containing an intentional admixture of lead for improving its machining characteristics is known as "*leaded brass*" or "lead brass." Alloys that contain more than 50 per cent zinc are usually designated as "zinc-base" alloys.

Brass of the general composition *60 per cent copper*, *40 per cent zinc* is widely known as "*Muntz metal*," but such names for specific compositions are less commonly applied to brasses than to bronzes. However, some specific terms may be very misleading. For example, the name "*German silver*" or "*nickel silver*" refers to the *white color* of the alloys, *not* to their *composition.* They are alloys of copper, nickel and zinc; they do not contain silver. Such compositions are more properly termed "nickel brasses," although their characteristic properties differ decidedly from those ordinarily associated with brass. *According to a decision of the United States Federal Trade Commission (Docket 1479, February 6, 1928) the words "nickel silver" should not be used to advertise or describe alloys which do not actually contain both of these metals.*[2]

Examples of the improper application of the term "bronze" are found in the alloys known as "architectural bronze," "manganese bronze," and "bronze" screen wire cloth. "Manganese bronze" is basically a copper-zinc alloy with improved mechanical properties and corrosion resistance because of the presence of small amounts of iron, tin, manganese, and aluminum. The name "high tensile brass" for such alloys, as used recently by the Copper Development Research Association (London), is highly commendable. "Architectural bronze" is essentially a simple leaded brass, used for decorative purposes. "Bronze" screen wire cloth is a simple brass containing 90 per cent copper and 10 per cent zinc. There is no metallurgical justification whatsoever for calling such material "bronze."

An illustration of confusion in nomenclature is encountered in the widely used alloy "85 and three 5's," 85 per cent copper, 5 tin, 5 zinc and 5 lead. This alloy is as frequently called "valve bronze" as it is "red brass"; it is also known as "ounce metal" because the constituents are in the ratio of 1 ounce of each to about 1 pound of copper. This alloy is a "brass" according to the specifications of the American Society for Testing Materials; it is listed as "red brass" in Specifications B 30 – 36 and "composition brass" or "ounce metal" in Specifications B 62 – 36. On the basis of structure, there is good reason for calling this alloy a bronze and it appears in the list of bronzes covered by Federal Specification QQ-B-691 for Casting Bronzes. Another alloy on this same list of bronzes, however, contains 80 per cent copper, 13 zinc and 4.5 tin. Numerous other examples of nonuniformity and inconsistency in naming alloys of this general type in specifications might easily be cited.

Bronze.—Alloys of copper and tin have been known since the dawn of history as "bronze." Except for a very few alloys, including bell metals, speculum metal, and certain special bronze files, the tin content is normally well below 20 per cent.

The use of simple binary alloys of copper and tin is quite limited; it is customary to add zinc and often lead to make these alloys, particularly in cast form, better fitted for industrial use. Such alloys containing from 10 to about 30 per cent lead, regardless of any zinc present, are known as "leaded bronze" and are widely used in bearings. The name "zinc bronze" has been used to some extent for copper-tin alloys modified by the admixture of zinc but for brevity the word "zinc" is often omitted and the material referred to simply as "bronze." Two widely used alloys in this class are the "88-10-2" alloy (88 per cent copper, 10 tin and 2 zinc) and its modern counterpart, the "88-8-4" alloy.

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[2] AUTHOR'S NOTE.—Under dates of November 15, 1930, and November 29, 1930, the Federal Trade Commission dismissed complaints made in accordance with the above decision and by a majority ruling declared that the use of the descriptive term "nickel silver" is legitimate.

"*Phosphor-Bronze*".—This name indicates that phosphorus was used as a deoxidizer during melting. Such a treatment usually confers superior properties on the alloy although chemical analysis often fails to show more than a trace of phosphorus in the finished material.

"*Government Bronze*".—There is a widespread but erroneous belief that there is a definite composition officially accepted by the Federal Government as the "best" bronze. One of the alloys of longest commercial use is the "88-10-2" alloy, containing 88 per cent copper, 10 tin, and 2 zinc. In the days when cannon were made of bronze this was known as "gun bronze," and for many years this alloy appeared as "Composition G" in the United States Navy Specifications. It also appeared in Specifications B 10 – 18 of the American Society for Testing Materials, but these specifications are now replaced by B 60 – 36 for the 88-8-4 alloy, which also appears in the list of bronzes for castings covered by Federal Specification QQ-A-691. Although this composition is, on the whole, a better all-around alloy for many purposes than the 88-10-2, it is not to be designated a "Government bronze" any more than any of the others covered by Federal Specifications.

In the field of "statuary bronzes" or "art bronzes," there is a similar erroneous idea that there is a preferred "government bronze." It appears that in 1895, in a letter by an individual purchasing officer concerning the Hancock statue, it was specified that the "U. S. Standard bronze to be used should consist of 90 parts of copper, 7 parts of tin, 3 parts of New Jersey refined spelter." Some of the firms receiving the letter, assuming that this phraseology had legal effect, designated this composition as "U. S. Standard" and used this term in somewhat the same manner as the terms "sterling silver" or "eighteen-carat gold" are used. Numerous cases can be cited to show that, even in its statuary purchases, the Federal Government has not adhered to this so-called "standard." One illustration is the bronze group in front of the Library of Congress which is made of an alloy of 90 per cent copper, 8 tin, 2 lead. Noted statues vary so in composition that it is clear that there are no fixed "ideal proportions" for art bronze, as well as no "U. S. Government Standards."

Other Bronzes.—Examples of the tendency to apply the name "bronze" to copper alloys other than those containing tin, are found in "aluminum bronze," "silicon bronze," and "conductivity bronze."

Aluminum Bronze.—The alloy having the approximate composition, 90 to 93 per cent copper, 7 to 10 per cent aluminum, with perhaps a little iron, is generally known as "aluminum bronze." It lacks the characteristic bronze color but has superior corrosion resistance and high strength. Other than trade names, the use of which should be discouraged, no descriptive name appropriate from the metallurgical standpoint has been suggested. The name "aluminum bronze" appears in Federal Specifications and in those of the American Society for Testing Materials and other technical societies.

Silicon Bronze.—This name is often applied, for lack of a better one, to a class of high-strength copper alloys which have recently received much attention. The name "copper-silicon alloy" is used in the Federal Specifications QQ-C-591 and 593, and suggests silicon as the essential alloying constituent. However, other alloying elements, manganese, zinc, iron, and tin are often present and the percentage of some of these may equal the silicon content. These alloys are outstanding in many respects and their commercial use, particularly in wrought forms, is rapidly increasing.

Conductivity Bronze.—This name is often used to designate alloyed copper for which a combination of high tensile strength and relatively high electrical conductivity is required. Cadmium and tin are the best alloying elements for the purpose, and are generally used in amounts somewhat below 2 per cent. With respect to the degree to

> which the conductivity of copper is lowered by the admixture of another element, cadmium is decidedly superior to tin.
>
> *Other Uses for the Term "Bronze."*—The term "bronze" is widely used as descriptive of the surface appearance of metals, especially with reference to the decorative effect. The designation of a leaded brass as "architectural bronze" is justified only on this basis. Certain decorative surface effects are described as "bronzed"; such a one is that given to steel by copper plating it and then treating it with a sulfide solution. Another use is in reference to the metallic pigments used in "bronzing paints." Finely divided metal in the form of flaky particles, whether copper, copper-zinc alloy or aluminum, is termed "bronze." . . . .
>
> With such looseness of terminology, and such a wide range of alloys in use, it is obvious that statistics of production of "brass" and "bronze" may not be used with great certainty or exactness for such purposes as attempting to calculate the amount of tin or zinc entering into the products.

Some four or five years ago, the author undertook to collect the necessary material and prepare the non-ferrous section of the Cast Metals Handbook of the American Foundrymen's Association. This work proved particularly arduous due to the confused terminology in the field and the absence of a standard classification of the copper-base alloys.

A short time later, the author undertook to prepare a small foundry handbook or casting manual to be published by *The Metal Industry*. Again the difficulty was encountered.

That this difficulty was not new or unrecognized by the Society is indicated by Specifications B 30 - 36. In that specification we see the general terms red brass, semi-red brass, leaded bronzes, high-leaded bronzes and yellow brasses used. However, they are used only as headings under each of which a few alloys are listed. No specific limits are set up as to the dividing lines between classes. The actual classes set up cover only a portion of the field and in fact do not cover some of the regular A.S.T.M. copper-base foundry or casting alloys.

In preparing the 1938 revision of the Casting Manual, the author undertook to set up a complete classification system with a complete terminology and a complete set of definitions to cover the copper and copper alloy field as applied to foundry work. Based upon such a system, it became possible to discuss in the manual entire classes of alloys instead of dealing with hundreds of minor alloy deviations.

It seems that the tentative system as presented first in the 1938 "Casting Manual" met with some favor from men in the industry who had long been troubled with the same problem. It was suggested that the Society's Committee B-5 on Copper and Copper Alloys, Cast and Wrought, undertake a study of the subject to see what could be done. For this work, the author was asked to act as chairman of a special sub-subcommittee functioning under Subcommittee X on Copper-Base Alloys for Sand Castings. The author immediately enlisted the help of the entire membership of Subcommittee X. The classification as finally evolved is being presented to the Society this year for publication as tentative.[3]

The classification is based on the use of the term "brass" as applicable to copper-zinc alloys and the term "bronze" as applicable to copper-base alloys containing alloying elements other than zinc, and in sufficient amounts to be predominant over zinc in effect on the properties. It is obvious then, that this proposed terminology recognizes "bronze" as the general term for copper-base alloys containing less than 98 per cent of copper and that the term "brass" then is really a particular kind of bronze, namely, a zinc-bronze.

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[3] See Tentative Classification of Cast Copper-Base Alloys (B 119 - 39 T) of the American Society for Testing Materials, 1939 Book of A.S.T.M. Standards, Part I.

The general classification is appended hereto.[3] It will be noted that in the class of "Copper" is included all alloys containing 98 per cent or more of copper which, therefore, includes in the class of copper many of the high electrical and high thermal conductivity copper-base alloys regularly produced in non-ferrous foundries. It will be noted that under the general heading of "Brass" there are subheadings of "Red Brass," "Semi-Red Brass," "Yellow Brass," "High-Strength Yellow Brass," "Nickel Brass," and "Silicon Brass." Subheadings under these various general headings could be added to cover those modified alloys which are essentially one of the major classes but have been changed by the addition of small amounts of addition agents desired to obtain certain specific properties. Thus any of the brasses may be leaded or not leaded. Some of the brasses may contain small amounts of tin, iron, aluminum, manganese, and nickel to give certain particularly desired properties. The addition of these modifying agents, however, in the order of a fraction up to 1 or 2 per cent is not considered as taking them out of the general classification of brass meaning a zinc-copper alloy.

Under the general heading of "Bronzes" then we have the typical tin bronzes which are further subdivided into the straight tin bronzes, the leaded tin bronzes, and the high leaded tin bronzes. In each case, these bronzes may be somewhat further modified and certain subclasses set up where small amounts of other metals have been added to produce certain specific changes in final properties. Passing then from the high-leaded tin bronzes, we have the straight lead bronzes, meaning the high-lead copper alloys containing essentially only lead and copper as used for bearing purposes and containing less than 5 per cent of tin. Further types of bronzes are then the nickel bronzes, aluminum bronzes, silicon bronzes and beryllium bronze.

As new and special alloys are developed, such as those capable of heat treatment, they should receive careful consideration and a name or classification assigned to them only after due consideration of the technical implications involved.

It is hoped that this system and this terminology will meet general acceptance by both the producing and consuming interests and that it will be used by engineers and purchasing agents and by and in the sales and advertising field as it applies to the casting field for copper and copper-base alloys.

It would not be difficult to set up a similar system for the wrought copper alloy field. Some systematization in that field would seem to be quite in order.

It would not be difficult to set up a system for the aluminum-base alloy field, both cast and wrought, when, as, and if the number of alloys in use in that field require it.

The system for the cast copper and copper alloys in the foundry field has now advanced from the baby in swaddling clothes as first seeing the light of day in the 1938 Casting Manual to the young lad as you see him today in the form of a tentative standard. His future is not yet assured. It is in your hands and the lap of Providence. I bespeak your kindness.

REPORT OF COMMITTEE B-6 ON DIE-CAST METALS AND ALLOYS

Committee B-6 on Die-Cast Metals and Alloys held two meetings during the year: one in Atlantic City, N. J., on July 1, 1938, and one in Columbus, Ohio, on March 9, 1939, with an attendance of 30 and 21, respectively. The subcommittees have also held meetings at various times during the year.

The following additions and changes in membership have been approved:

J. B. Neiman, Federated Metals Division of American Smelting and Refining Co.,
Walter Bonsack, The National Smelting Co.,
S. E. Maxon, replacing W. W. Broughton, The New Jersey Zinc Co., resigned,
W. A. Cowan, National Lead Co., resigned,
Marc Stern, A. C. Spark Plug Division of General Motors Corp., resigned, and
J. G. G. Frost, formerly of The National Smelting Co., now connected with the Aluminum-Magnesium Corp., Sandusky, Ohio, has not applied for reinstatement following change in employment and was therefore dropped from membership in accordance with Society regulations.

At the present time the committee consists of 77 members, 62 of whom are voting members; 26 are classed as producers, 20 as consumers, and 16 as general interest members.

A balance of $179.42 is reported by Society Headquarters in the fund of Committee B-6 as of December 31, 1938.

REVISION OF TENTATIVE STANDARDS

The committee recommends revisions of three tentative specifications as follows:

Tentative Specifications for Lead and Tin-Base Alloy Die Castings (B 102 – 35 T):[1]

Section 2.—In the table of chemical composition requirements change the tin content for alloy No. 2 from "82 per cent" to read "80 to 84 per cent," and the copper content from "5 per cent" to read "4.0 to 6.0 per cent."

Section 3.—Following the table of permissible variations add a note to read as follows:

> NOTE.—The permissible variations do not apply to tin or copper contents for alloy No. 2 specified in Section 2.

Tentative Specifications for Aluminum-Base Alloy Die Castings (B 85 – 37 T):[2]

Section 7.—In the table of chemical composition requirements change the maximum permissible zinc content of alloy No. VII from "0.8 per cent" to read "1.0 per cent."

Change the composition requirements for alloy No. VIII to read as follows by the addition of the italicized figures and the omission of those in brackets:

Desired Composition, per cent:		
Copper		1.5
Silicon	[1]	*0.75*
Nickel		2.25
Aluminum	[95.25]	*95.5*
Permissible Variations, per cent:		
Copper		1.0 to 2.0
Silicon	[0.8 to 2.0]	*0.5 to 1.0*
Nickel	[1.8 to 2.5]	*1.75 to 2.5*
Other Elements, max., per cent:		
Iron	[2.5]	*2.0*
Zinc	[0.8]	*0.5*
Manganese		0.3
Magnesium		0.10
Tin		0.1
Total other impurities		0.2

Change the maximum permissible zinc content of alloy No. XII from "1.5 per cent" to read "1.8 per cent," and the maximum permissible tin content from "0.1 per cent" to read "0.3 per cent."

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 753 (1935); also 1938 Book of A.S.T.M. Tentative Standards, p. 423.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 705 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 420.

Change footnote *b* to read as follows by the addition of the italicized words and the omission of the word in brackets:

> Analysis shall ordinarily be made only for the elements [specifically] mentioned in this table. If, however, the presence of other elements is *suspected or* indicated in the course of routine analysis, further analysis shall be made to determine that these other elements do not exceed the total given in the last column.

Appendix.—At the end of the appendix add a sentence to read as follows:

> When tension tests are made, they should be made at a free running testing machine head speed of approximately ¼ in. per min. and the tests carried out at ordinary room temperature.

Tentative Specifications for Magnesium-Base Alloy Die Castings (B 94 – 37 T):[3]

Section 1.—Change the second sentence to read as follows by the addition of the italicized words and the omission of those in brackets:

> [One alloy is] *Two alloys are* specified and [is] *are* designated as alloy*s* No*s*. 12 *and 13*.

Section 3.—Change the table of chemical composition requirements from its present form to read as follows:

	Alloy No. 12	Alloy No. 13
Magnesium, per cent	remainder	remainder
Aluminum, per cent	9.0 to 11.0	8.3 to 9.7
Manganese, min., per cent	0.10	0.13
Zinc, per cent	0.3 max.	0.4 to 1.0
Silicon, max., per cent	1.0	0.5
Copper, max., per cent	0.05	0.05
Nickel, max., per cent	0.03	0.03
Other ingredients (cadmium, tin), max., per cent	0.3	0.3

Explanatory Notes.—In Note 1 change the first sentence to read as follows by the omission of the words in brackets:

> The data in the following table [covering alloy No. 12] do not constitute a part of these specifications.

Change the table of physical properties from its present form to read as follows:

Alloy	Tensile Strength, psi.	Elongation in 2 in., per cent	Charpy Impact, ft-lb.
No. 12	29 000 to 34 000	1 to 3	0.5 to 2
No. 13	29 000 to 34 000	2 to 5	1 to 3

Change Note 2 from its present form to read as follows:

> NOTE 2.—Alloy No. 12 has a specific gravity of about 1.81. It has been widely used because it combines good physical properties with good casting characteristics. The copper and nickel contents should be kept low to minimize corrosion.
>
> Alloy No. 13 has a specific gravity of about 1.81. It has good casting characteristics, approximately the same resistance to salt-water corrosion as alloy No. 12 and better physical properties. The copper and nickel contents should be kept low to minimize corrosion.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
REVISIONS OF TENTATIVE STANDARDS			
Specifications for Lead and Tin-Base Alloy Die Castings (B 102 – 35 T)	38	0	13
Specifications for Aluminum-Base Alloy Die Castings (B 85 – 37 T)	42	0	7
Specifications for Magnesium-Base Alloy Die Castings (B 94 – 37 T)	42	0	9

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 62 voting members; 56 members returned their ballots, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum-Base Die-Casting Alloys (E. E. Thum, chairman) is working on the exposure tests of aluminum-base alloys of higher than commercial purity. In general, the results of the tests indicate that the appearance of aluminum-silicon alloy die castings exposed for 4 yr. in an industrial atmosphere is not greatly influenced either by the silicon content (5 or 12 per cent) or by the purity (high *versus* commercial). In a marine atmosphere, there is a definite, but not substantial advantage in using high-purity alloys but there appears to be little difference between the 5 and 12 per cent silicon alloys. Regardless of the purity and silicon content, the alloys are corroded by an interdendritic type of attack and to an average depth in 4 yr. of about 0.003 to 0.005 in. The maximum depth of attack during this period of exposure is about twice the average depth, and again regardless of purity or silicon content. The differences noted in this test between specimens cast by two different producers appear to be within experimental error. Although it is evident from these results that the exposure has been too short to show definitely the differences between the high-purity and standard alloys, the visual examina-

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[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 708 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 425.

TABLE II.—CHEMICAL ANALYSES OF ZINC ALLOY DIE-CAST TEST BARS.

Alloy	Producer	Composition, per cent							
		Aluminum	Copper	Magnesium	Lead	Cadmium	Iron	Tin	Nickel
No. XXI	A	4.2[a]	2.8[a]	0.04[c]	0.002[b]	<0.002[b]	0.012[c]	<0.001[b]	<0.005[b]
	D	3.8	2.8	0.05	0.002	<0.002	0.015	<0.001	<0.005
	J	4.2	2.8	0.05	0.001	<0.002	0.019	<0.001	<0.005
	P	3.8	2.6	0.05	0.001	<0.002	0.026	<0.001	<0.005
	S	4.1	3.0	0.06	0.002	<0.002	0.019	<0.001	<0.005
	Z	4.3	2.8	0.04	0.002	<0.002	0.025	<0.001	<0.005
No. XXIII	A	4.0[a]	<0.01[c]	0.05[c]	0.002[b]	<0.002[b]	0.018[c]	<0.001[b]	<0.005[b]
	J	4.2	<0.01	0.05	0.001	<0.002	0.006	<0.001	<0.005
	P	3.8	<0.01	0.04	0.001	<0.002	0.010	<0.001	<0.005
	Z	4.1	<0.01	0.05	0.002	<0.002	0.016	<0.001	<0.005
No. XXV	A	4.1[a]	1.1[a]	0.04[c]	0.001[b]	<0.002[b]	0.018[c]	<0.001[b]	<0.005[b]
	D	3.9	1.0	0.05	0.002	<0.002	0.010	<0.001	<0.005
	J	4.2	1.1	0.05	0.001	<0.002	0.010	<0.001	<0.005
	P	3.9	1.0	0.05	0.002	<0.002	0.019	<0.001	<0.005
	S	4.2	1.0	0.06	0.001	<0.002	0.009	<0.001	<0.005
	Z	4.0	1.0	0.04	0.002	<0.002	0.013	<0.001	<0.005

[a] Chemical analyses.
[b] Spectrographic analyses.
[c] Analyzed by chemical and spectrographic methods.

TABLE III.—PHYSICAL PROPERTIES OF ZINC ALLOY DIE-CAST TEST BARS.

Alloy	Producer	Original Properties (Specimens Aged 3 to 6 Months)						Exposed to 95 C. Steam for 10 Days				
		Tensile Strength, psi.	Charpy Impact, ft-lb.	Izod Impact, ft-lb.	Brinell Hardness	Rockwell Hardness	Elongation in 2 in., per cent	Tensile Strength, psi.	Charpy Impact, ft-lb.	Izod Impact, ft-lb.	Elongation in 2 in., per cent	Expansion in 6 in., in.
No. XXI	A	47 700	26	>26	92	95	11	43 400	1	1	2	0.0108
	D	49 800	>31	>29	108	98	5	44 300	1	1	1	0.0124
	J	47 000	30	>27	96	94	8	43 100	1	2	2	0.0081
	P	45 700	26	>30	96	95	7	41 900	2	3	2	0.0081
	S	52 300	23	>25	98	97	16	47 200	1	1	1	0.0148
	Z	49 100	>38	>26	100	96	12	44 900	1	1	2	0.0128
No. XXIII	A	37 000	>33	>23	69	84	17	33 800	27	>18	12	0.0021
	J	36 500	>40	>23	66	82	12	33 300	30	>16	11	0.0026
	P	36 500	>41	>25	67	82	15	32 800	26	>17	16	0.0027
	Z	37 700	>43	>23	74	85	15	34 200	37	>17	14	0.0029
No. XXV	A	44 100	>42	>26	85	92	10	38 300	13	>17	5	0.0014
	D	46 700	>44	>27	91	92	4	37 900	8	>11	5	0.0015
	J	42 200	>41	>25	84	89	6	36 600	6	>18	3	0.0016
	P	42 900	>38	>27	84	89	6	36 800	14	>18	5	0.0013
	S	45 600	>37	>24	90	91	8	38 800	6	5	5	0.0018
	Z	44 200	>46	>24	91	91	9	37 900	9	>12	6	0.0022

tion, and to a lesser extent the depth of attack measurements, show a slight superiority for the high-purity grades.

A special subgroup appointed to review the composition limits specified in the Tentative Specifications for Aluminum-Base Alloy Die Castings (B 85 – 37 T) has prepared the changes being recommended in certain of the alloys covered by these specifications.

Subcommittee II on Zinc-Base Die-Casting Alloys (C. E. Heussner, chairman) has reviewed the Tentative Specifications for Zinc-Base Alloy Die Castings (B 86 – 38 T) and feels that the specifications should be retained for the present in their tentative status. The subcommittee is considering the addition to the specifications of two appendices which have been proposed by Subcommittee IV on Physical Tests of Die Castings, relating to the speed at which tension tests shall be made and notations covering the use of tension test data for engineering designs.

TABLE IV.—CHEMICAL ANALYSES OF MAGNESIUM-ALLOY DIE-CAST TEST BARS.

Alloy	Producer	Composition, per cent							
		Aluminum	Silicon	Manganese	Zinc	Cadmium	Tin	Copper	Nickel
No. 307	H......	6.3	0.2	0.14	0	0	0	0.01	0
	K......	6.6	0.1	0.24	0	0	0	<0.01	0
	M.....	6.5	0	0.19	0.1	0	0	<0.01	0
No. 312	H......	8.9	0.2	0.14	0	0	0	0.01	0
	K......	9.4	0.3	0.24	0	0	0	<0.01	0
	M.....	10.3	0.4	0.14	0	0	0	<0.01	0
No. 313	H......	8.5	0.2	0.14	0.4	0	0	0.01	0
	K......	8.6	0	0.22	0.6	0	0	<0.01	0
	M.....	8.6	0	0.18	0.5	0	0	<0.01	0
No. 314	H......	6.9	0.2	0.14	1.8	0	0	0.02	0
	K......	6.4	0	0.33	2.3	0	0	<0.01	0
	M.....	6.4	0	0.20	2.5	0	0	<0.01	0

Subcommittee III on Tin- and Lead-Base Die-Casting Alloys (G. O. Hiers, chairman) completed its plans for the production of additional sets of test specimens for the exposure tests on lead- and tin-base alloys. One additional producer has cast test bars of five lead- and tin-base alloys. The present plans call for the testing of these test bars for tensile strength by three laboratories. Creep studies are also to be made on the test bars and, if possible, spectrographic analyses will be conducted by four laboratories on the test specimens. A report containing results of the chemical analysis and tension tests of the five alloys studied is appended hereto.

Subcommittee IV on Physical Tests of Die Castings (R. L. Templin, chairman) has suggested to the other subcommittees of Committee B-6 that speed and temperature of tension tests be controlled by specific requirements. The subcommittee is now actively working on a revision of the methods for impact testing of die-cast specimens.

TABLE V.—PHYSICAL PROPERTIES OF MAGNESIUM-ALLOY DIE-CAST TEST BARS.

Alloy	Producer	Original Properties (Specimens Aged 3 to 6 Months)			
		Tensile Strength, psi.	Charpy Impact, ft-lb.	Rockwell Hardness	Elongation in 2 in., per cent
No. 307	H........	29 100	2	64	4
	K........	34 200	4	67	7
	M.......	26 200	4	66	3
No. 312	H........	30 200	1	74	2
	K........	32 700	2	78	2
	M.......	33 100	1	82	1
No. 313	H........	29 600	1	72	2
	K........	32 000	2	75	4
	M.......	26 500	3	75	1
No. 314	H........	26 600	2	70	1
	K........	33 200	3	69	7
	M.......	28 500	3	72	3

Subcommittee V on Exposure and Corrosion Tests (W. M. Peirce, chairman) is actively conducting atmospheric corrosion tests on die-casting alloys. The first atmospheric tests were started in 1929 and have been continued 10 yr. Other specimens have been removed from the exposure racks and tested after exposure periods of 1 yr. and 5 yr. The tests were originally scheduled to terminate at the end of the 10-yr. period.

After reviewing the progress of the corrosion work the subcommittee recommended to Committee B-6 that the aluminum-alloy test bars remain on the exposure racks, both outdoors and indoors, for at least another 5 yr. The racks containing the zinc-alloy specimens have been recalled in accordance with the schedule previously set up, primarily because all of the alloys now on exposure are commercially obsolete with the exception of alloy No. XXI. Specimens of alloy No. XXI will not be tested at this time, but will be re-exposed, along with the new zinc and magnesium alloys now being placed on exposure racks, for at least another 5 yr. at the same locations where they have been for the past 10 yr. One round tension bar of alloy No. XXI from each producer and from each exposure location has been withheld from re-exposure for microscopic examination. Measurements have been made on the impact bars to determine the dimensional changes that have occurred to date.

The atmospheric exposure test racks for the three new zinc and four magnesium alloys cast in the late summer of 1938 are now in the process of assembly. The analyses and original physical property test data on the zinc and magnesium alloys, and the ten-day, 95 C. steam data for the zinc alloys appear in Tables II to V.

Subcommittee VII on Magnesium-Base Die-Casting Alloys (J. A. Gann, chairman) has reviewed the Tentative Specifications for Magnesium-Base Alloy Die Castings (B 94 – 37 T) and is recommending the inclusion of a new alloy No. 13 and certain minor revisions in the requirements for alloy No. 12, as mentioned earlier in this report. The subcommittee is considering the addition to these specifications of two appendices recommended by Subcommittee IV relative to the speed at which the tension tests shall be made.

A paper on "Magnesium Alloy Die-Castings" by A. W. Winston of the Dow Chemical Co. appears as an appendix to this report.

This report has been submitted to letter ballot of the committee which consists of 62 voting members; 58 members returned their ballots, of whom 56 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. R. TOWNSEND,
Chairman.

G. L. WERLEY,
Secretary.

REPORT OF SUBCOMMITTEE III ON TIN- AND LEAD-BASE DIE-CASTING ALLOYS

This report presents the results of the preliminary tests obtained in the investigation of lead- and tin-base alloy die-cast test specimens which have been undertaken by Subcommittee III. This investigation was accomplished through the cooperation of two die casters and four other companies who supplied the ingot metal. Two of the ingot metal suppliers also furnished chemical analyses of the finished die castings. Tension tests were made by two of the ingot metal suppliers while a third laboratory participated in the physical tests.

TABLE I.—SPECIFIED REQUIREMENTS FOR CHEMICAL COMPOSITIONS OF LEAD- AND TIN-BASE ALLOYS.

Alloy	Tin, per cent			Antimony, per cent			Lead, per cent			Copper, per cent			Iron, max., per cent	Arsenic, max., per cent	Zinc, max., per cent	Aluminum, max., per cent
	Min.	Desired	Max.	Min.	Desired	Max.	Min.	Desired	Max.	Min.	Desired	Max.				
No. 1	90	91	92	4	4.5	5	..	..	0.35	4	4.5	5	0.08	0.08	0.01	0.01
No. 2	80	82	84	12	13	14	..	..	0.35	4	5	6	0.08	0.08	0.01	0.01
No. 3	64	65	66	14	15	16	17	18	19	1.5	2	2.5	0.08	0.15	0.01	0.01
No. 4	4	5	6	14	15	16	79	80	81	..	..	0.50	..	0.15	0.01	0.01
No. 5	..	..	..	9.25	10	10.75	89	90	91	..	..	0.50	..	0.15	0.01	0.01

Cooperator C die cast flat tension specimens and ¼ by ¼-in. square impact specimens of the five alloys listed in Table I and supplied ingot metal for alloys Nos. 1, 4, and 5. Cooperator F furnished ingot metal for alloys Nos. 2 and 3. Cooperator D die cast the round tension specimens and the ¼ by ¼-in. square impact specimens of the five alloys which were supplied in ingot form as follows: Cooperator A supplied alloys Nos. 1, 2, and 3, while cooperator B supplied alloys Nos. 4 and 5.

Cooperators B, E, and F conducted the tensile strength and elongation tests on the tension specimens while cooperators A and B furnished the chemical analyses of the fractured tension specimens. Impact tests have also been made but the results have not yet been released.

Specified requirements for the chemical compositions of the alloys studied in this investigation are listed in Table I, while the actual analyses of the fractured tension specimens are given in Table II. The results of the tension tests are recorded in Table III.

Respectfully submitted on behalf of the subcommittee,

G. O. Hiers,
Chairman.

TABLE II.—CHEMICAL ANALYSES OF FRACTURED TENSION SPECIMENS.

Alloy	Specimens	Analysts	Tin, per cent	Antimony, per cent	Lead, per cent	Copper, per cent	Iron, per cent	Arsenic, per cent	Zinc, per cent	Aluminum, per cent
No. 1	Flat	A.......	90.91	4.76	0.12	4.04	0.04	0.04	<0.01	0.001
	Flat	B.......	90.44	4.5	0.14	4.34		0.04		
	Round	A.......	92.42	4.84	0.29	2.26	0.03	0.06	<0.01	0.001
	Round	B.......	92.2	5.0	0.14	2.45		0.05		
No. 2	Flat	A.......	81.81	12.94	0.47	4.62	0.06	0.01	<0.01	0.001
	Flat	B.......	81.48	12.9	0.13	4.84		0.04		
	Round	A.......	84.02	12.98	0.12	2.76	0.02	0.008	<0.01	0.001
	Round	B.......	82.8	13.2	0.10	3.0		0.05		
No. 3	Flat	A.......	66.06	15.05	16.68	2.00	0.05	0.055	<0.01	0.001
	Flat	B.......	65.40	15.0	17.02	2.20		0.04		
	Round	A.......	66.11	14.27	18.01	1.42	0.02	0.07	<0.01	0.001
	Round	B.......	66.0	14.1	17.8	1.70		0.05		
No. 4	Flat	A.......	4.81	14.88	80.13	0.02	0.02	0.09	<0.01	0.001
	Flat	B.......	4.70	15.4	79.6	0.14		0.06		
	Round	A.......	4.93	14.60	80.20	0.14	0.02	0.085	<0.01	0.001
	Round	B.......	5.0	14.6	79.80	0.30		0.07		
No. 5	Flat	A.......	0.21	8.88	90.73	0.04	0.01	0.04	<0.01	0.001
	Flat	B.......	....	8.8	90.6	0.10		0.04		
	Round	A.......	0.06	9.85	89.90	0.09	0.02	0.06	<0.01	0.001
	Round	B.......	....	9.8	89.8	0.20		0.05		

TABLE III.—RESULTS OF TENSION TESTS.

Testing Laboratory	Alloy No. 1				Alloy No. 2				Alloy No. 3				Alloy No. 4				Alloy No. 5			
	Sb 4.9 Cu 2.3		Sb 4.65 Cu 4.2		Sb 13 Cu 2.9		Sb 13 Cu 4.7		Round Specimen		Flat Specimen		Round Specimen		Flat Specimen		Round Specimen		Flat Specimen	
	Round Specimen		Flat Specimen		Round Specimen		Flat Specimen													
	Tensile Strength, psi.	Elongation in 2 in., per cent	Tensile Strength, psi.	Elongation in 2 in., per cent	Tensile Strength, psi.	Elongation in 2 in., per cent	Tensile Strength, psi.	Elongation in 2 in., per cent	Tensile Strength, psi.	Elongation in 2 in., per cent	Tensile Strength, psi.	Elongation in 2 in., per cent	Tensile Strength, psi.	Elongation in 2 in., per cent	Tensile Strength, psi.	Elongation in 2 in., per cent	Tensile Strength, psi.	Elongation in 2 in., per cent	Tensile Strength, psi.	Elongation in 2 in., per cent
E.....	10000	20.2	9420	15.4	13010	15.8	12570	8.4	11370	4.1	9590	1.4	10600	4.6	9740	4.5	7840	10.2	7700	7.2
B.....	10520	23.6	10040	14.7	14240	14.4	13600	2.9	12380	2.5	10700	0.5	11560	7.7	10300	2.6	7990	13.7	7990	2.7
F.....	10407	23.0	9452	17.7	13175	12.5	13290	7.5	11665	4.7	10114	1.8	10615	6.0	10230	4.0	7851	9.8	7941	6.5

Testing Laboratory	Type of Testing Machine	Capacity, lb.	Range Used, lb.	Grips	Rate of Free Moving Cross Head, in. per min.	Temperature During Test
E..............	Amsler hydraulic	20 000	0 to 1 000	Standard	0.25	72 F.
B..............	Tinius Olsen four-screw rotating gear unit	20 000	0 to 2 000	Standard	0.50	85 F.
F..............	Tinius Olsen three-screw rotating gear unit	50 000	0 to 5 000	Self aligning for flat specimen. Standard for round specimen	0.30	76 F.

NOTE 1.—Round specimens of alloys Nos. 1 and 2 were inadvertently cast at 550 F. while the liquidus is about 150 F. higher. Accordingly, the copper content is definitely lower than the limit specified.

NOTE 2.—The round specimens were about 3 months old when tested. The flat specimens were about 8 months old when tested by laboratory B and about 20 months old when tested by laboratories E and F.

NOTE 3.—All laboratories tested six specimens for each of the above derived arithmetic averages. The round specimens of the lead- and tin-base alloys were sounder or were less porous than the flat specimens. This is in line with the specimens studied in the development of the zinc-base die-casting alloys.[1] A few specimens obviously defective due to porosity gave low results which were not included in the averages.

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[1] G. L. Werley, "A Study of Die Design Changes for the Improvement of the Soundness and Uniformity of Test Bars," Appendix, Report of Committee B-6, *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 223 (1937).

APPENDIX

MAGNESIUM ALLOY DIE CASTINGS

By A. W. Winston[1]

At least from a practical standpoint, the art of die casting magnesium alloys in this country is entirely a development of the last ten years.

Proceeding from the usual spasmodic experimental phases at the beginning, the industry has grown, particularly since 1935, to a position commanding the respect of all interested in the subject. At the present time there are six companies regularly producing magnesium-alloy die castings, making them available in all consuming sections of the country.

The first significant work, according to available records, was early in 1931, when Mr. Charles Pack cast a number of alloys experimentally in a cold chamber machine and in dies designed for the high-pressure casting of brass. The metal was poured into the chamber of the machine at the lowest possible ladling temperature. This was roughly controlled by keeping a stick of solid metal in the melting pot at all times. The castings produced were satisfactory in appearance and the test bars yielded very impressive properties, not greatly different from the best obtainable today.

Machine Development

Low-Pressure Machines:

In spite of this favorable beginning, the method did not receive much attention during the next few years which were devoted to attempts to cast in goose-neck machines. While the latter process was by no means unsuccessful, the operation difficulties were considerable and discouraging enough to retard rapid progress. The major problem may be mentioned. As is generally well known, magnesium alloys will oxidize rapidly in contact with air at temperatures much above the melting point of approximately 1200 F. This necessitated the use of protective fluxes or an inert atmosphere over the metal in the melting pot and the use of an inert atmosphere in the goose-neck. There was a constant struggle to maintain adequate protection at the operating temperature and at the same time avoid contamination of the casting with flux or dross. As magnesium alloys have a low heat capacity and as the casting air pressure, for safety reasons, had to be limited to 400 psi., it was necessary to cast at about 1400 F. in order to get fairly sound castings. The high temperature also made impractical the goose-neck and plunger type of machine either with ports or separate valves.

High-Pressure Machines:

After a thorough and careful study of the air-operated goose-neck machine, the conclusion was inevitable that some other casting method should be developed, whereupon, work was started on the cold chamber method. The first large-scale attempt was a modification of a side gate automatic goose-neck machine, whereby the melting pot and goose-neck below the dies were replaced by the pressure chamber. The closure of the dies took place after filling the chamber, a rather slow operation resulting in premature solidification of the magnesium alloy. Mechanical troubles also developed in attempting to hold the dies together against the high fluid pressure (1500 psi.) developed during

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[1] The Dow Chemical Co., Midland, Mich.

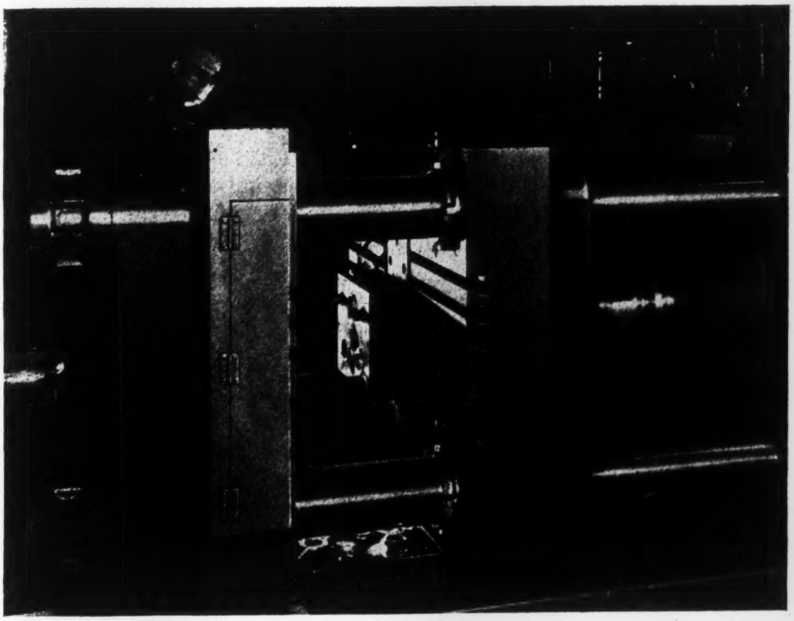
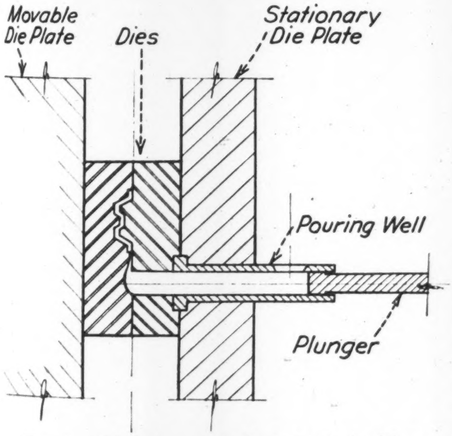
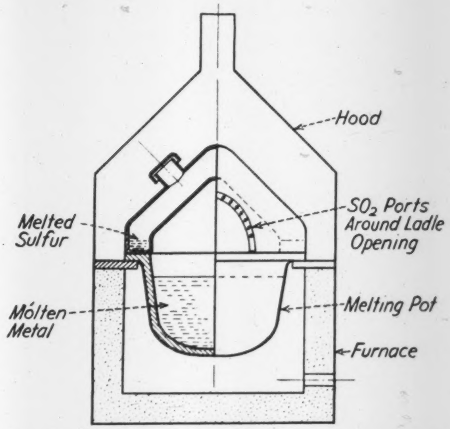


FIG. 1.—Modern Cold Chamber Die Casting Machine for Magnesium Alloys.



Movable Die Plate
Dies
Stationary Die Plate
Pouring Well
Plunger

FIG. 2.—Diagrammatic Sketch of Machine Shown in Fig. 1.



Hood
Melted Sulfur
SO2 Ports Around Ladle Opening
Molten Metal
Melting Pot
Furnace

FIG. 3.—Melting Pot and Protecting System for Die Casting Magnesium Alloys.

the shot. It was immediately apparent, however, that the cold chamber process offered tremendous possibilities. The surface finish, density, and strength were greatly improved, while production efficiencies and costs began to approach reasonable figures. A center gate machine with pouring well located at the end outside the stationary die plate was then built. While a considerable improvement, trouble was still experienced with excessive "flash" due to inadequacy of the hydro-mechanical mechanism for locking the dies.

The machine shown in Figs. 1 and 2 was finally built, and has been in very satisfactory operation ever since. The dies are held together by direct hydraulic pressure, a total capacity of 500 tons being available for the purpose. An air-hydraulic accumulator furnishes oil at 1000 psi. for the pressure stroke of the injection ram. The main cylinder of the machine is filled from a low-pressure air-hydraulic accumulator for the free stroke, with direct pumping up to 2000 psi. for the actual clamping of the dies. Core pulls usually are hydraulically operated. A special valve mechanism permits rapid operation with a minimum of lost time between steps. The 7-in. tie rods are of ample size to carry the die-locking load and the added pressure during the "shot."

The die clamping capacity of the machine should permit the making of castings with a projected area of 200 sq. in. Castings of this size are regularly made, such as the baker's peel shown in Fig. 8 with an area of 234 sq. in. Castings up to 74 in. in length also have been made as shown in Fig. 9. While massively constructed, the machine is flexible in operation and has operated at as high as 100 cycles per hour on medium-sized castings at a casting efficiency of 97 per cent.

While the machine just described has been quite satisfactory, other designs should perform well also and, in fact, are doing so at the present time. The important requirements are strength and rigidity in the machine and rapid filling of the die through well-placed gates.

OPERATING PRACTICE

Melting and Casting:

Just as important as the actual die-casting machine are the means employed for melting and holding the magnesium alloy at the casting temperature. Both the open pot method and the crucible method in use in magnesium-alloy sand foundries are unsuitable, as protection from surface oxidation is here obtained by the use of flux over the exposed surface of the metal. Numerous devices were tried, the design shown diagrammatically in Fig. 3 finally being adopted. The cast steel melting pot of 400-lb. capacity is surmounted by a double-walled domed cover, partially filled with sulfur. The heat from the pot causes the sulfur to melt and sulfur vapor to distill through the holes surrounding the ladle opening in the side of the cover. These vapors burn on contacting the air, introducing a small amount of sulfur dioxide into the air within the cover. This effectively inhibits active oxidation between the melting point of about 1100 F. and the operating temperature of not more than 1300 F. Additional protection is occasionally given as necessary by throwing within the cover a pinch of sulfur or of a mixture of sulfur, ammonium silicon fluoride, and boric acid (Dow Agent No. 14).

A small amount (1 to 3 per cent) of a heavy flux (Dow Flux No. 22A) is melted with the original charge of metal ingots. When the metal is melted, it is stirred to assist the flux to coagulate any dirt or dross that may be present.

After settling, the sludge is removed by a perforated skimmer. The metal is ready for use after a short additional settling period. During use the metal is fluxed occasionally depending on the amount and condition of the metal being added and the oxidation occurring in operation.

A round-bottomed ladle of the correct size for the casting being made is used to transfer the metal from the pot to the well of the die-casting machine, the shot being made immediately thereafter. The usual pouring temperature range is 1175 to 1250 F. Occasionally for some castings it is necessary to go to 1300 F., but if this does not seem to be high enough the remedy is sought in improved gating.

The finishing of magnesium alloy die castings presents few problems, the methods used for other metals generally being applicable with little modification. Machining is easily accomplished, usually dry, but with an oil-type coolant for high-speed operations if very accurate dimensions must be maintained.

Scrap from casting and machine operations should not be remelted for die casting directly. The preferred procedure is to refine by the "open pot" method in the presence of a large quantity of flux (Dow No. 23A), recasting into 3-lb. ingots.

The over-all metal efficiency is approximately 90 per cent for large to medium-sized castings. For small castings, the efficiency will be slightly less due to the relatively larger proportion of butts and sprues to be refined. Casting efficiencies vary but will average about 95 per cent. Castings with a wall thickness of $\frac{3}{32}$ in. or more will run consistently better than those with thinner walls.

Dies:

Dies for casting magnesium alloys may be made from a number of tool steels on the market. For relatively short runs a carbon tool steel is satisfactory. For long die life a tool steel of the 5 per cent chromium, 6 per cent tungsten type has been found satisfactory. The dies should be heat treated and drawn to a Brinell hardness of about 450. The drawing temperature should be 1000 to 1100 F. so that the dies will not soften in use.

Due to their low heat capacity, magnesium alloys tend to solidify quickly. After pouring, it is necessary, therefore, to get the metal into the die as soon as possible and consistent with adequate venting to avoid entrapped air. Experience has indicated that gating and venting satisfactory for aluminum alloys will usually require some modification in adapting dies to magnesium alloys.

Die temperatures ordinarily run from 250 to 500 F., with 350 F. as a good average temperature. Water cooling usually is not necessary although it may be for very high production operations. Freedom from surface swirls and cold shuts is possible only when dies are maintained at the proper temperatures. The dies gradually become coated with a thin film of oxide making other die coatings unnecessary. Too high die temperatures cause excessive oxide film on the dies and rough surface on the casting.

Sizes and Tolerances:

The limitation on maximum size of castings will be dependent, of course, upon the equipment available. The machine illustrated in Fig. 1 is capable of producing castings of 6 lb. in weight, and as has been mentioned earlier of at least 230 sq. in. of projected area and up to 74 in. in length. The minimum wall thickness successfully cast has been 0.040 in. but this was over a rather small area. A more practical minimum is 0.050 in. A useful approximate rule for wall thicknesses up to 0.130 in. has been $\frac{1}{1000}$ of the surface area. Thus the minimum thickness for an area of 100 sq. in. would be 0.100 in. Numerous exceptions to this rule occur, however, due to casting design and the relation of the area in question to the gates.

TABLE I—NOMENCLATURE AND COMPOSITION OF MAGNESIUM DIE-CASTING ALLOYS.

A.S.T.M. (B 80 – 39 T)[a] Alloy	The Dow Chemical Co.	American Magnesium Corp.	Doehler Die Casting Corp.	The Hoover Co.	H. L. Harvill, Inc.	Nominal Composition, per cent				
						Aluminum	Manganese	Silicon	Zinc	Magnesium
No. 12	Dowmetal K	AM230	......	....	Dowmetal K	10.0	0.13	0.5	....	Remainder
No. 13	Dowmetal R	AM263	10	....	Dowmetal R	9.0	0.13	....	0.6	Remainder
	Dowmetal AX	AM241	......	Dowmetal AX	....	8.0	0.15	0.3	....	Remainder
	Dowmetal EX	....	6	Dowmetal EX	Dowmetal EX	6.0	0.2	0.2	....	Remainder

[a] 1939 Book of A.S.T.M. Standards, Part I.

TABLE II.—TYPICAL MECHANICAL PROPERTIES AND CHARACTERISTICS OF MAGNESIUM DIE-CASTING ALLOYS.

Alloy	Tensile Strength, psi.	Yield Strength, psi.	Elongation in 2 in., per cent	Brinell Hardness	Impact Izod, ft-lb.	Characteristics and Uses
Dowmetal K	30 000	22 000	1	62	1	Highest yield strength, but being replaced by Dowmetal R.
Dowmetal R	33 000	21 000	3	60	2	Best die-casting alloy. Good casting characteristics with high mechanical properties and good corrosion resistance.
Dowmetal AX	32 000	20 000	3	60	2	Largely replaced by Dowmetal R composition.
Dowmetal EX	27 000	17 000	4	50	3	Used where maximum toughness is desired.

Yield strength is defined as the stress at which the stress-strain curve deviates 0.2 per cent from the modulus line. Mechanical properties are obtained on standard A.S.T.M. die-cast specimens.

The following tolerances generally apply to magnesium die castings:

Tolerance per inch of dimension	±0.0015 in.
Minimum tolerance within solid die	±0.003 in.
Minimum tolerance across parting line or between solid die and movable die parts	±0.005 in.

In some cases the casting design may permit closer tolerances than those given.

CHARACTERISTICS OF MAGNESIUM ALLOY DIE CASTINGS

Effect of Pressure:

The upper limit of desirable working pressure for magnesium alloys has not been established definitely. The difference between 200 and 1000 psi. is easily apparent in the soundness of the casting, but the difference is not very significant between 4000 and 6000 psi. The subject, of course, is associated with many other factors, including casting design, gating practice, metal and die temperatures, and alloy composition. Generally speaking, no special advantage seems to be obtained with pressures over 4000 psi.; in fact, some castings are made satisfactorily with much less. The test bars reported in Table II and most of the castings shown in the figures were made at approximately 4000 psi.

Effect of Composition:

The castability of magnesium alloys is affected by the composition, particularly in regard to hot shortness and the resulting shrinkage cracking in sharp interior corners and over cores. The die-casting alloys are basically magnesium with 6 to 10 per cent aluminum

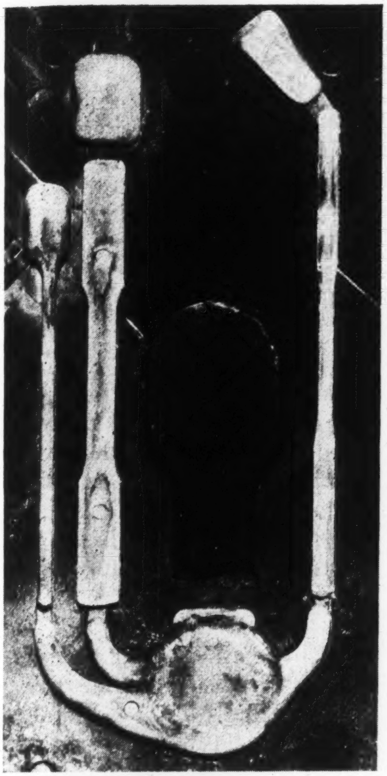


FIG. 4.—Die for Magnesium Alloy Die Cast Test Bars.

and 0.10 to 0.15 per cent manganese. Amounts up to 0.5 per cent silicon or 0.6 per cent zinc are also added to increase the fluidity and improve the surface. The former raises the yield strength slightly but with a loss in ductility, while the latter increases the ductility with little effect on the yield strength. The addition of zinc in amounts above one per cent is not practical because of excessive hot shortness, although simple castings and test bars have been made with as high as 3 per cent zinc (Dowmetal H: magnesium, 6 per cent aluminum, 3 per cent zinc, 0.15 per cent manganese). Within the limits given earlier, the composition has but slight effect upon the surface quality and soundness of the die casting when made by the "cold chamber" process. Other factors apparently of more importance are metal and die temperatures, metal pressure, and gating methods. The castability of the commercial alloys, as far as surface quality is concerned, is in the order in which they are listed in Table I except that A.S.T.M. Alloys Nos. 12 and 13 are

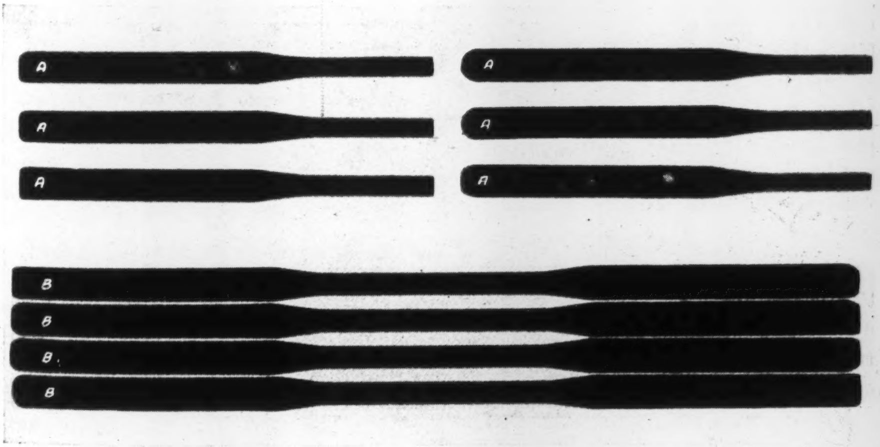


FIG. 5.—Radiograph of Dowmetal Test Bars.

A—Cast at 300 psi.
B—Cast at 4000 psi.

about the same. Tables I and II list the designations, nominal compositions, typical mechanical properties, and characteristics of the alloys.

The mechanical properties given are somewhat higher than those obtained several years ago, even with the same die-casting machine. This has been brought about by study and improvement of the gating method for the test bar die, the latest revision of which is shown in Fig. 4. The radiographs in Fig. 5 show the soundness it is possible to secure in bars today, contrasted to the results formerly obtained with low-pressure casting in a goose-neck machine.

A question frequently asked is: Can magnesium alloy die castings be heat treated? The first three alloys listed in Table I can be solution heat treated with considerable increase in ductility and some falling off in yield strength. However, while present-day castings are remarkably sound and free from porosity, no casting is perfect and there is just enough porosity remaining to cause occasional blistering on heating to 700 F. or higher. A better solution, if ductility is required, is to reduce the aluminum content as in Dowmetal EX (Table I).

While the yield strength of magnesium alloy die castings is almost uniformly satisfactory, some interest has been shown in alloys with very high proportional limit and yield strength. Experimental work with a large number of alloys has shown that this is possible by a combination of solution and aging heat treatments. In the production of castings, blistering during the solution heat treatment would have to be eliminated as much as possible by reducing the porosity to a minimum with careful gating and operation control. The properties given below are typical of the results obtained:

PROPERTIES OF DIE-CAST DOWMETAL, HEAT TREATED AND AGED

(Mg, 12 Al, 0.7 Si, 0.7 Zn, 0.1 Mn)

Tensile strength, psi	42 200	42 000
Yield strength (0.2 per cent set), psi	29 300	29 000
Proportional limit, psi	16 900	17 000
Elongation in 2 in., per cent	0.8	
Impact value, ft-lb	0.8	
Brinell hardness	88	

STABILITY AND METHODS FOR FINISHING

Stability:

Magnesium alloy die castings are remarkably stable under ordinary conditions of rural and urban exposure, provided there is free drainage and ventilation to allow the parts to dry normally. In locations of high humidity and high temperature, as in the tropics, a smooth surface will gradually tarnish and eventually roughen with the formation of a thin oxide or hydroxide film.

In steam at atmospheric pressure, the formation of the hydroxide film proceeds more rapidly and in a few days the piece will be entirely covered with a loosely adherent coating of magnesium hydroxide. It has not yet been established whether or not the orthodox steam test is of any value when applied to magnesium die castings. At higher steam temperatures and pressures, the rate of film formation is further increased and the coating becomes more dense. If the film is formed in dilute caustic soda solution at high temperature and pressure, it is very dense and adherent and is the basis of a protective and decorative treatment described later as Dow Treatment No. 6. Die castings so treated resist remarkably well subsequent exposure to steam or marine atmospheres.

Service performance and exposure tests show that in industrial and urban atmospheres magnesium alloys equal and often excel other structural metals with higher salt water resistance. Die

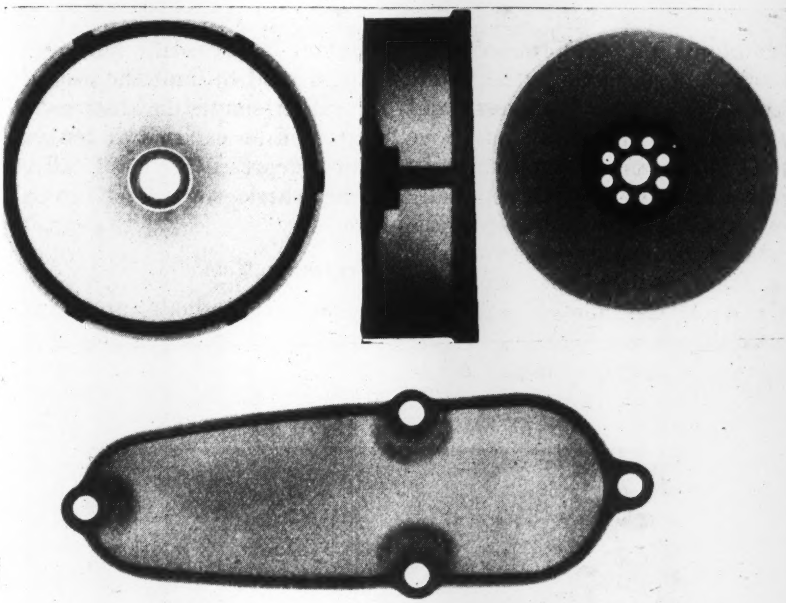


FIG. 6.—Radiograph of Dowmetal Die Castings.

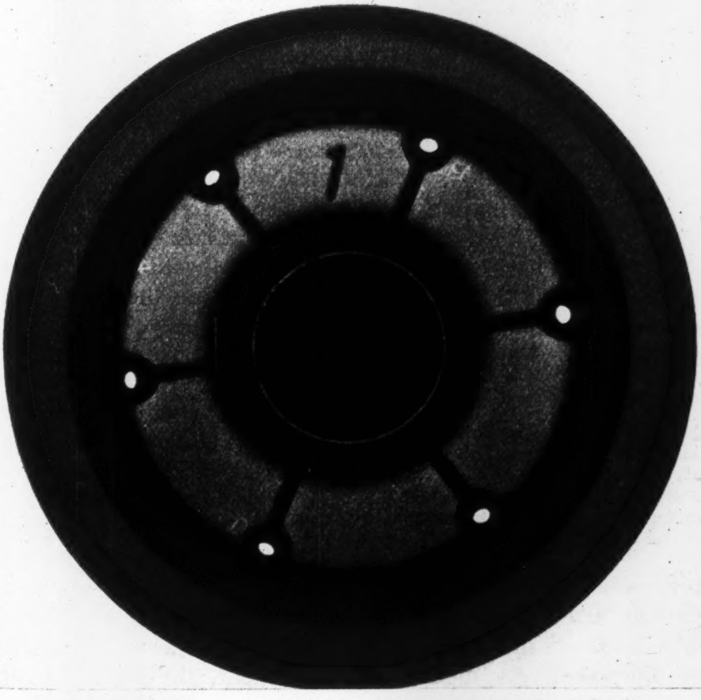


FIG. 7.—Radiograph of Die Cast Dowmetal Airplane Wheel.

castings possess the best salt water resistance of the various forms of magnesium alloys, surpassing the same compositions in sand castings and wrought forms. The die-casting alloys listed in Table I are of approximately equal resistance. If material especially resistant to salt water is required, die castings can be made of Dowmetal M (magnesium with 1.2 per cent manganese). While this alloy is weldable, the properties are not high and its use is restricted to lightly stressed applications.

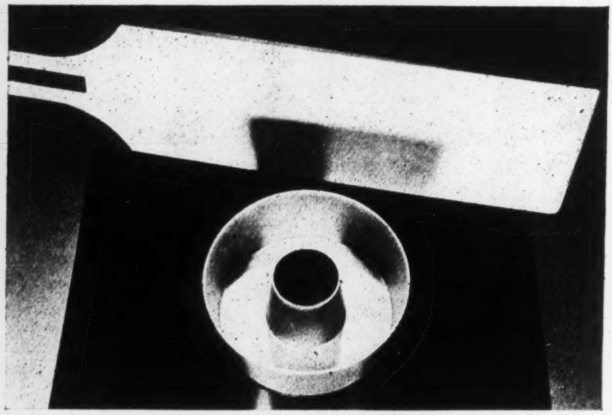


FIG. 8.—Die Cast Dowmetal Baker's Peel and Cake Pan.

In order that more information may be available on the stability under different conditions, the Society's Committee B-6 on Die-Cast Metals and Alloys is starting atmospheric exposure tests of four die cast compositions, as follows:

1. A.S.T.M. Alloy No. 12 (see Table I)
2. A.S.T.M. Alloy No. 13 (see Table I)
3. Dowmetal EX (see Table I)
4. Dowmetal H (6 per cent aluminum, 2.5 per cent zinc, 0.15 per cent manganese, remainder magnesium.

The last composition ordinarily is used for sand castings rather than die castings, but was included in the test for comparative purposes. As mentioned earlier in this paper, the high zinc content increases the hot shortness and would tend to limit the use of the alloy to rather simple die castings. The test bars will be exposed at ten testing stations representative of all types of atmospheric conditions throughout the country.

Finishing Methods:

Several methods are available for finishing magnesium-alloy die castings, either for protection or decoration. As the usual paints do not adhere well when applied directly, some preliminary treatment ordinarily is necessary. Paint products, particularly primers, should be tested for their performance under the conditions of service. In addition to standard paint materials, the very large variety of novelty finishes all may be used to produce almost any desired effect. These include wrinkle finishes, crystallizing and veiling lacquers, flock finishes, metal effects, etc.

For indoor and ordinary outdoor service, most castings are treated with the chrome-pickle, applied either by the manufacturer or by the customer after machining. In the chrome-pickle treatment, the parts are dipped for 5 sec. at 120 F. in a solution containing 1.5 lb. of sodium dichromate and 1.5 pints of concentrated nitric acid per gallon. The surface receives a light etch which promotes the adhesion of subsequent paint finishes, while the coating imparts a considerable degree of salt-water resistance.

Two alternatives exist for the use of the above treatment for indoor or ordinary atmospheric exposure. The first is the use of a special air dry primer which has proved satisfactory when applied to bare or untreated metal. It is, however, rather slow drying. The second is the use of baking paint systems which have shown good adhesion to bare metal and are particularly adapted to the finishing of large quantities of die castings for indoor service.

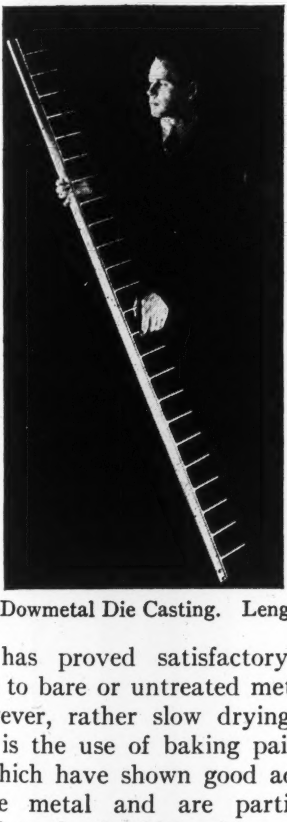


FIG. 9.—Dowmetal Die Casting. Length 74 in.

For exposure to marine atmospheres, the casting after machining should receive the Dow No. 7 or No. 8 treatments, neither of which affects machined dimensions. The coatings produced impart a high degree of salt-water resistance to the complete system, including the paint coatings. The paint primer should be of the zinc chromate inhibitive type and should be followed by three finish coats of a synthetic resin enamel. Both treatments, No. 7 and No. 8, are acceptable to government air services for the treatment of magnesium alloy die castings.

Treatment No. 7 consists of a 5-min. dip in 15 per cent hydrofluoric acid followed by a 45-min. boil in a 10 per cent sodium dichromate solution. The die castings assume a dark gray to brownish-black finish. The process is included in Army Air Corp Specification No. 98-20010-A for the treatment of magnesium alloy parts for Army aircraft.

Treatment No. 8 described below does not quite equal No. 7 in protective value in salt water. After a 5-min. dip in 15 per cent hydrofluoric acid, the parts are boiled 45 min. in a solution containing per gallon:

Ammonium sulfate	4 oz. (3.0 per cent)
Sodium dichromate	4 oz. (3.0 per cent)
Ammonia (sp. gr. 0.880)	$\frac{1}{3}$ fluid oz. (0.25 per cent)

The coating is then sealed by boiling 5 min. in a 1 per cent solution of arsenous oxide. The coating is somewhat blacker than that produced by the No. 7 treatment and this may be desired for certain applications. The treatment is acceptable for Naval aircraft parts, being covered by Navy Aeronautical Specification M-382.

Another treatment of interest to users of magnesium die castings is Dow No. 6, in which the parts are immersed in an autoclave for a short time in 10 per cent caustic soda solution at 225 psi. pressure and at approximately 390 F. The oxide or hydroxide coating is dense, hard, and adherent. It may be dyed with a choice of colors ranging from neutral through yellow, brown, green, red, blue, or bronze, producing very attractive decorative effects. The treatment is recommended for parts requiring protection and abrasion resistance in the unpainted condition, as for instance, the interior of aircraft carburetor parts. Exterior surfaces can be painted with a fair degree of adhesion using approved primers.

The finishing of magnesium alloy die castings by buffing and polishing is not common due to the tendency of the metal to darken and tarnish. Where such finish is required, the polish may be preserved by the use of a lacquer especially developed for the purpose.

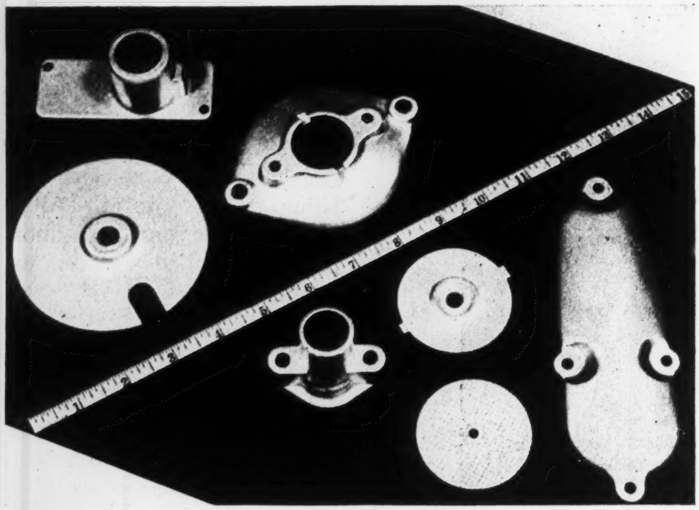


FIG. 10.—Die Cast Dowmetal Aircraft and Portable Tool Parts.

Until recently, the electroplating of magnesium alloys was not considered practical. However, some success has attended experimental efforts in this direction. It is quite possible that methods will be developed in the near future which will make the processes available for production use.

In general, it may be said that the finishing of magnesium alloy die castings does not involve any unusual problems, in that treatments and materials are available for the vast majority of applications.

APPLICATIONS

The applications for magnesium alloy die castings naturally are those in which weight is an important factor. This will be understood when it is realized that aluminum is 50 per cent heavier, cast iron and zinc four times, and brass five times heavier than magnesium alloy parts of the same volume. The combination of the low specific gravity of 1.8 with the properties given in Table II indicates a strength-weight ratio unsurpassed among die-cast metals.

The aircraft industry has made use of magnesium die castings for several years in such engine parts as rocker box covers and shroud tube fittings and for instrument parts including some for the "automatic pilot." Some of these are illustrated in Fig. 10. Conduit fittings and many other applications are being studied at the present time. Interest in the whole field is indicated by the fact that Navy Aeronautical and Army Air Corps Specifications have recently been issued covering magnesium alloy die castings used in aircraft. These specifications are respectively, M-369 and No. 11319.

The automobile industry has been slower to begin the use of magnesium alloy die castings because of the competitive price situation. One large manufacturer, however, has a project under way at the present time using upward of 6000 castings a day in generator and starting motor parts.

instruments (Figs. 10, 11, 12). Typewriter and other business machines, textile machines, and other automatic machinery all are users of magnesium die castings (Fig. 13). Novel uses in the baking industry are the baker's peel and the "angel food" cake pan shown in Fig. 8.

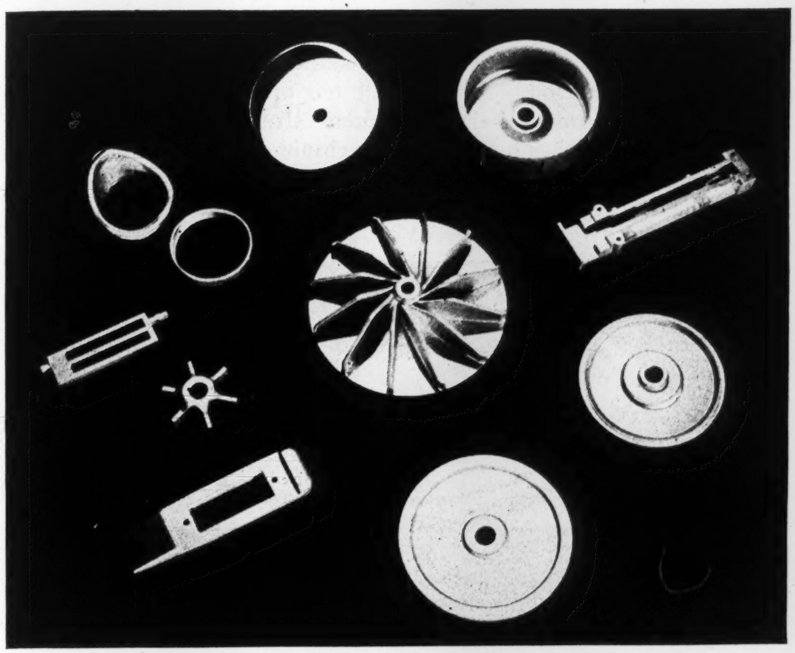


FIG. 11.—Miscellaneous Dowmetal Die Castings.

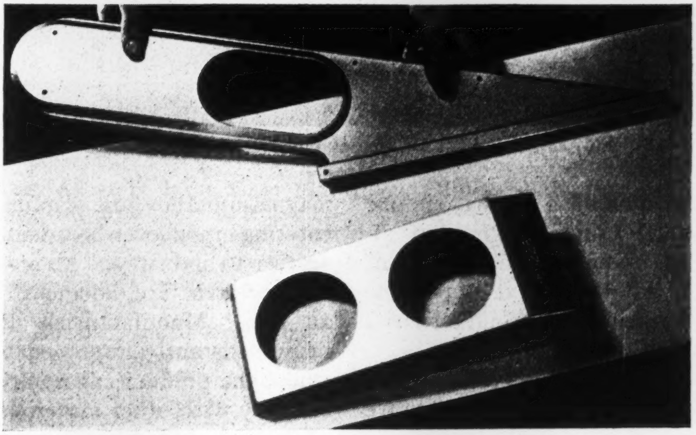


FIG 12.—Die Cast Dowmetal Instrument Housings.

Other applications in which weight is significant in saving labor are vacuum cleaners, motion picture cameras, binocular frames, instrument cases, goggle frames, portable tools and musical

As production experience is gained,

costs are being steadily reduced until in many cases the prices for magnesium alloy die castings are on a competitive basis. In other applications, competition does not truly exist between magnesium alloys and other materials as the heavy weight of the latter eliminates them from consideration.

A highly specialized form of die casting is in the rotors for induction electric motors. The end rings and conductor bars through the steel laminations are cast in place, making a strong, simple, and economical unit. Magnesium alloys are used frequently, not for their light weight, but because it is possible to get certain electrical conductivities desired for high torque motors.

The design of parts as magnesium alloy die castings does not involve radically new principles. Attention should be paid to details such as careful filleting of junctions, adequate support for rivets, bolts, or studs, and ample number of such fastenings. Sharp interior angles should be avoided. Loading should be in line with the maximum ability to support the load: eccentric loading always brings undesirable stress concentration. These ideas are not new and apply to all materials, but are all too often forgotten in the drafting room. Intelligent design and careful machining will do much to eliminate troubles in service.

In conclusion it may be said that magnesium-alloy die castings are just entering upon ever-broadening fields of service to industry. Alloys and finishing methods are adequate for almost all uses. Manufacturing methods are being constantly improved to the point where the product can compete unquestionably with other materials on a price basis. Numerous applications belong to magnesium alloys alone because of their unique combination of strength and light weight.

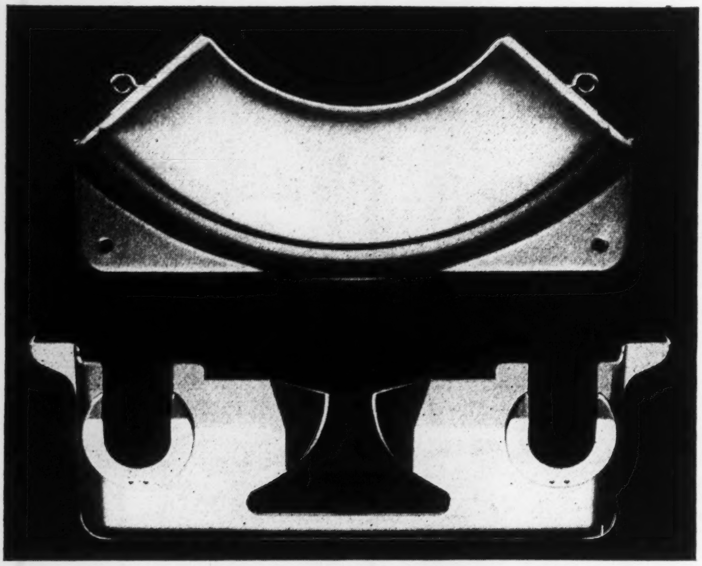


FIG. 13.—Die Cast Dowmetal Typewriter Cover Plates.

REPORT OF COMMITTEE B-7

ON

LIGHT METALS AND ALLOYS, CAST AND WROUGHT

Two meetings of Committee B-7 on Light Metals and Alloys have been held during the past year: one in Atlantic City, N. J., on June 30, 1938, and the second in Columbus, Ohio, on March 6, 1939.

Several membership changes have been made since the 1938 annual meeting. Two members have submitted their resignations while two new members have been added, making no change in the total membership. Two company representatives have also been replaced by new members. The membership of the committee now totals 45, of whom 20 are classified as producers, 15 as consumers, and 10 as general interest members.

I. NEW TENTATIVE STANDARDS

The committee submits for publication as tentative the following three new specifications:[1]

Tentative Specifications for:

Aluminum-Base Alloys in Ingot Form for Die Castings, prepared in response to requests from die-casting manufacturers and users,

Aluminum Alloy Ingots for Remelting (B 24 - 39 T), representing a revision of Standard Specifications B 24, and

Aluminum for Use in Iron and Steel Manufacture (B 37 - 39 T), representing a revision of Standard Specifications B 37.

II. REVISIONS OF TENTATIVE STANDARDS

The committee recommends that the four tentative specifications listed below be revised in accordance with the details shown in the Appendix, and continued as tentative. In all cases these revisions have been recommended in order to bring the specifications in line with present commercial practices.

Tentative Specifications for:

Aluminum-Alloy (Duralumin) Sheet and Plate (B 78 - 36 T),

Aluminum-Alloy (Duralumin) Bars, Rods, and Shapes (B 89 - 36 T),

Magnesium-Base Alloy Ingot for Remelting (B 93 - 38 T), and

Aluminum-Magnesium-Chromium Alloy Sheet and Plate (B 109 - 36 T).

III. ADOPTION OF TENTATIVE STANDARD AS STANDARD

The committee recommends that the Tentative Specifications for Magnesium Ingot and Stick for Remelting (B 92 - 36 T)[2] be approved for reference to letter ballot of the Society for adoption as standard. These specifications have been published as tentative for three years without revision, and review of present commercial practice indicates that no changes are likely to be necessary within the next few years.

IV. WITHDRAWAL OF STANDARDS

The committee recommends the withdrawal of the following two standard specifications[3] since these standards are covered by new specifications now being proposed for publication as tentative:

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[1] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part I.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 704 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 326.

[3] 1936 Book of A.S.T.M. Standards, Part I, pp. 524 and 717.

Standard Specifications for:

Aluminum Ingots for Remelting (B 24 - 29), and

Aluminum for Use in the Manufacture of Iron and Steel (B 37 - 26).

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 45 members; 36 members returned their ballots, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Aluminum-Base Alloys in Ingot Form for Die Castings	31	1	4
Spec. for Aluminum Alloy Ingots for Remelting (B 24 - 39 T)	33	0	3
Spec. for Aluminum for Use in Iron and Steel Manufacture (B 37 - 39 T)	31	0	5
II. REVISIONS OF TENTATIVE STANDARDS			
Spec. for Aluminum-Alloy (Duralumin) Sheet and Plate (B 78 - 36 T)	28	0	8
Spec. for Aluminum-Alloy (Duralumin) Bars, Rods, and Shapes (B 89 - 36 T)	28	0	8
Spec. for Magnesium-Base Alloy Ingot for Remelting (B 93 - 38 T)	30	0	6
Spec. for Aluminum-Magnesium-Chromium Alloy Sheet and Plate (B 109 - 36 T)	28	0	8
III. ADOPTION OF TENTATIVE STANDARD AS STANDARD			
Spec. for Magnesium Ingot and Stick for Remelting (B 92 - 36 T)	32	0	4
IV. WITHDRAWAL OF STANDARDS			
Spec. for Aluminum Ingots for Remelting (B 24 - 29)	33	0	3
Spec. for Aluminum for Use in the Manufacture of Iron and Steel (B 37 - 26)	32	0	4

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum and Aluminum Alloy Ingots (D. L. Colwell, chairman).—This subcommittee held one meeting during the year and completed the new Specifications for Aluminum-Base Alloys in Ingot Form for Die Castings which it has submitted for publication as tentative. The subcommittee has also reviewed, in cooperation with interested representatives of various steel companies and standing committees of the Society having jurisdiction over specifications for iron and steel, the Standard Specifications for Aluminum for Use in the Manufacture of Iron and Steel (B 37 - 26) and is recommending that the specifications be replaced immediately by new specifications which are being submitted for publication as tentative. Subcommittee I expresses its appreciation of the cooperation given by the various steel companies in developing these new tentative specifications.

In addition, the Standard Specifications for Aluminum Ingots for Remelting (B 24 - 29) have been completely rewritten in the form of new tentative specifications to cover present commercial materials; the new specifications are to replace immediately the present Standard B 24.

Subcommittee II on Aluminum Alloy Castings (C. H. Greenall, chairman).—The study of the effect of variations in the major elements and impurities on the properties of aluminum-base alloys, being made by a subgroup of Subcommittee II, has been continued. Preliminary work is being confined to the 5 per cent silicon and the 8 per cent copper alloys. D. Basch, chairman of the subgroup, has also arranged for the organization of a subcommittee in the American Foundrymen's Association to cooperate on this study. A questionnaire requesting data is being prepared at the present time for circulating to foundries.

Subcommittee III on Aluminum Alloy Wrought Shapes (P. V. Faragher, chairman).—In order to bring the requirements of certain of the tentative specifications for wrought shapes into closer agreement with present commercial practices and with revised Government specifications for corresponding materials, Subcommittee III is recommending changes in the Tentative Specifications for Aluminum-Alloy Bars, Rods, and Shapes (B 89 – 36 T) and for Sheet and Plate (B 78 – 36 T and B 109 – 36 T), as given in detail in the Appendix.

Significant among these recommendations is the removal of clauses restricting the use of scrap and specifying a closer range of permissible composition limits, both of which are in accord with the practice followed in Government specifications. There is no adequate means for the purchaser to supervise the metal used in producing material to these specifications, and since his concern is only that the material conform to the composition and mechanical properties specified, regardless of the means taken to accomplish that result, restriction of the material used is unnecessary. Deletion of the permissible variations in dimensions for extruded shapes is recommended because the tolerances now quoted are not used by all producers.

Subcommittee IV on Magnesium and Magnesium Alloys (J. A. Gann, chairman).—In view of the fact that the Tentative Specifications for Magnesium Ingot and Stick for Remelting (B 92 – 36 T) have stood for three years without revision and commercial practice indicates no changes are probable within the next few years, this subcommittee has recommended that the specifications be adopted as standard.

One new die-casting alloy has also been recommended for addition to the Tentative Specifications for Magnesium-Base Alloy Ingot for Remelting (B 93 – 38 T). This alloy has found considerable use in industry and is used commercially by several producers. Details of these recommended changes are given in the Appendix.

Subcommittee V on Testing Light Metals (R. L. Templin, chairman).—This subcommittee has continued to cooperate with the Section on Effect of Speed of Testing of Committee E-1 on Methods of Testing. Specimens of two magnesium-base alloys and two aluminum-base alloys have already been supplied for these tests by the Dow Chemical Co., National Smelting Co., and Aluminum Company of America. Information has been received to the effect that the light alloy part of the program is to be initiated shortly.

Subcommittee VI on Anodic Oxidation of Aluminum and Aluminum Alloys (T. S. Fuller, chairman).—The Subgroup on Methods of Testing Anodic Coatings has continued its investigations of methods for determining various characteristics of such coatings. A new indirect method of determining the thickness of these coatings by weight per unit area, developed by the Aluminum Research Laboratories, has been submitted to members of the committee for test. A method of testing the sealing characteristics of oxide coatings has also been submitted to the committee for trial.

The determination of the abrasive resistance of these coatings is being given further attention, this work being facilitated by the availability of abrasimeters, as recommended by the subcommittee, to the three members of the subgroup. Some tests have also been made by a manufacturer of a rotating wheel abrasimeter, but careful examination of these data by the subcommittee has led to the conclusion that this instrument will not be as useful as the abrasimeter using an abrasive air-blast. The results obtained with this rotating wheel abrasimeter appeared to suffer from the same inconsistencies that have been observed in earlier tests made with instruments of this type.

Subcommittee VII on General Information and Publicity (E. H. Dix, Jr., chairman).—This subcommittee has given consideration to the question of revising the Report on Service Characteristics of the Light Metals and Their Alloys, published in 1934.[4] A majority opinion has been returned which does not favor revision or continuation of this report. The fact that this information is now available from many other sources has been cited as not justifying further work by the committee.

This report has been submitted to letter ballot of the committee which consists of 45 members; 36 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

SAM TOUR,
Chairman.

H. J. ROWE,
Secretary.

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part I, p. 277 (1934); also issued as separate publication.

EDITORIAL NOTE

Subsequent to the annual meeting Committee B-7 presented to the Society through Committee E-10 on Standards the following recommendations:

Proposed Tentative Specifications for Aluminum-Manganese Alloy Sheet and Plate for Use in Welded Pressure Vessels (B 126 – 39 T), and

Proposed Revision of Tentative Method of Test for Dielectric Strength of Anodized Aluminum (B 110 – 38 T).

These recommendations were accepted by Committee E-10 on August 24, 1939, and the new and revised tentative standards appear in the 1939 Book of A.S.T.M. Standards, Part I.

APPENDIX

PROPOSED REVISIONS IN STANDARDS FOR LIGHT METALS AND ALLOYS

In this Appendix are given proposed revisions in certain tentative specifications covering light metals and alloys which are referred to earlier in this report. In connection with each title is given the reference to the publication in which the specifications appear in their present form.

Tentative Specifications for Aluminum-Alloy (Duralumin) Sheet and Plate (Aluminum-Copper-Magnesium-Manganese) (B 78 – 36 T):[1]

Section 1.—Change from its present form: namely,

1. No scrap shall be used in the manufacture of aluminum-alloy (duralumin) sheet and plate except such as shall accumulate at the manufacturer's plants from material of similar composition and of his own manufacture.

to read as follows:

1. This material shall be produced in accordance with good commercial manufacturing practices and from metal which will permit compliance with the chemical composition and mechanical property limits prescribed in these specifications.

Section 2.—Change from its present form: namely,

Aluminum, min., per cent	92
Copper, per cent	3.5 to 4.5
Magnesium, per cent	0.2 to 0.75
Manganese, per cent	0.4 to 1.0

to read as follows:

	Minimum	Maximum
Aluminum, per cent by difference	...	remainder
Copper, per cent	3.5	4.5
Magnesium, per cent	0.2	0.75
Manganese, per cent	0.4	1.0
Iron, per cent	...	1.0
Silicon, per cent	...	0.75
Chromium, per cent	...	0.25
Other elements, each, per cent	...	0.03
Other elements, total, per cent	..	0.10

NOTE.—Analysis shall regularly be made only for the elements specifically mentioned in the above table. If, however, the presence of other elements is suspected, or indicated in the course of routine analysis, further analysis shall be made to determine that they are not present in excess of the amount specified.

Section 4.—Change the table of mechanical properties for "heat-treated" and "rolled-after-heat-treating" tempers from its present form to read as shown in the accompanying Table I.

TABLE I.

	Thickness, in.	Tensile Strength, min., psi.	Yield Strength, min., psi.	Elongation in 2 in., min., per cent	Bend Diameter Factor, *N*
Heat treated	0.010 to 0.020	55 000	32 000	15	3
	0.021 to 0.040	55 000	32 000	17	3
	0.041 to 0.128	55 000	32 000	18	4
	0.129 to 0.258	55 000	32 000	15	6
	0.259 to 0.500	55 000	32 000	12	8
	0.501 to 1.000	55 000	32 000	10	...
	1.001 to 1.500	55 000	32 000	9	...
	1.501 to 2.000	52 000	32 000	8	...
	2.001 to 3.000	50 000	32 000	6	...
Rolled after heat treating	0.020 to 0.031	55 000	42 000	10	3
	0.032 to 0.040	55 000	42 000	11	3
	0.041 to 0.064	55 000	42 000	12	4
	0.065 to 0.128	55 000	42 000	12	5
	0.129 to 0.188	55 000	42 000	12	8

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, pp. 690, 680 (1936); also 1938 Book of A.S.T.M. Tentative Standards, pp. 301, 290.

Tentative Specifications for Aluminum-Alloy (Duralumin) Bars, Rods, and Shapes (Aluminum-Copper-Magnesium-Manganese) (B 89 – 36 T):[1]

Title.—Change the title by the addition of the word "Wire" to appear after "Rods."

Section 1.—Change from its present form: namely,

> 1. No scrap shall be used in the manufacture of the material except such as may accumulate in the manufacturer's own plants from material of similar composition and of his own manufacture.

to read as follows:

> 1. This material shall be produced in accordance with good commercial manufacturing practices and from metal which will permit compliance with the chemical composition and mechanical property limits prescribed in these specifications.

Section 2.—In the table of chemical composition requirements appearing in this section make the same change as recommended above in Tentative Specifications B 78 – 36 T.

Table I.—In the heading of this table add the word "Wire" after the word "Rods." For rounds, squares, hexagons, and octagons in sizes 3.001 to 8.000 in. in diameter or distance across flats, change the minimum yield strength requirement from "28,000 psi." to read "30,000 psi."; also for rectangular sections, 0.751 to 3.000 in. in thickness, change the minimum yield strength requirement from "28,000 psi." to read "30,000 psi."

Table III.—Delete the permissible variations for "Shapes, Extruded" and add a note to read as follows:

> NOTE.—The permissible variations on the dimensions of shapes produced by extrusion shall be as agreed upon between the manufacturer and the purchaser.

Tentative Specifications for Magnesium-Base Alloy Ingot for Remelting (B 93 – 38 T):[2]

Section 1.—Change the third sentence to read as follows by the addition of the italicized word and figure and the omission of the word in brackets:

> [Thirteen] *fourteen* alloys are specified and are designated alloys Nos. 1, 2, 3, 4, 6, 7, 8, 9, 11, 12, *13*, 14, 15, and 16 (Note 2).

Section 3.—Add to the table of chemical composition requirements, alloy No. 13 having the following chemical requirements:

Magnesium, per cent	remainder
Aluminum, per cent	8.5 to 9.5
Manganese, min., per cent	0.15
Zinc, per cent	0.5 to 0.9
Copper, max., per cent	0.04
Silicon, max., per cent	0.2
Other impurities,[a] max., per cent	0.3

[a] Nickel, max. 0.02 per cent.

Tentative Specifications for Aluminum-Magnesium-Chromium Alloy Sheet and Plate (B 109 – 36 T):[3]

Section 2.—Change from its present form: namely,

> 2. No scrap shall be used in the manufacture of aluminum-magnesium-chromium alloy sheet and plate except such as shall accumulate at the manufacturer's plants from material of similar composition and of his own manufacture.

to read as follows:

> 2. This material shall be produced in accordance with good commercial manufacturing practices from metal which will permit compliance with the chemical composition and mechanical property limits prescribed in these specifications.

Section 3.—Change the second sentence of Note 1 following the table of chemical composition requirements to read as follows by the addition of the italicized words and the omission of those in brackets:

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[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 662 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 328.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 36 Part I, p. 699 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 311.

If, however, the presence of other elements is *suspected, or* indicated in the course of routine analysis, further analysis shall be made to determine that [the total of these other elements is] *they are* not present in excess of the [limits] *amount* specified [in Section 3].

Section 5 (*b*).—Change from its present form: namely,

(*b*) *Plate.*—Unless otherwise specified, plate in thicknesses 0.250 in. and over shall be supplied as rolled (see Explanatory Note 2) and tension tests shall not be required. If so specified, plate shall be supplied in the soft temper in thicknesses from 0.250 to 3.000 in., in which case the tensile strength shall not exceed 31,000 psi. and the elongation shall not be less than 20 per cent in 2 in.

to read as follows:

(*b*) *Plate.*—Unless otherwise specified, plate in thicknesses 0.250 to 3.000 in. shall be supplied as rolled (See Explanatory Note 2) and tension tests shall not be required. If so specified in the purchase order, plate shall conform to the following mechanical properties for the temper as specified.

Temper	Thickness, in.	Tensile Strength, psi.	Elongation in 2 in., min., per cent
Annealed	0.250 to 3.000	34 000 max.	12
Half-hard	0.250 to 0.999	34 000 min.	8
Quarter-hard	1.000 to 2.000	31 000 min.	9

Explanatory Notes.—Change Note 2 from its present form to read as follows:

NOTE 2.—Aluminum-chromium-magnesium alloy plate is commercially available in thicknesses from ¼ to 3 in., inclusive. Plate is normally rolled hot to the specified thickness. Because of the cooling during the rolling process, there is some strain hardening of the metal, particularly in the thinner gages. The tensile strength and hardness are always at least equal to those of the soft temper and in thicknesses up to ⅝ in. the mechanical properties average around those of the quarter-hard to half-hard tempers. The yield strength in these thicknesses is at least 50 per cent greater than that of the soft temper. The tensile strength of plate in the soft temper is usually somewhat higher than that of annealed sheet; it is regularly not less than 26,000 psi. and averages about 31,000 psi.; its yield strength is not less than 10,000 psi. and averages about 13,000 psi.

REPORT OF JOINT COMMITTEE ON EXPOSURE TESTS OF PLATING ON THE NON-FERROUS METALS

INCLUDING A FEW TESTS ON STEEL

Introduction:

This report summarizes the conclusions reached by the Joint Committee on the exposure tests started in 1936 and 1938. The details regarding the base metals and coatings are contained in the previous reports of this committee.[1] The details of the investigation will be published as a Research Paper of the National Bureau of Standards.

During the coming year the committee hopes to prepare specifications for plated coatings on non-ferrous metals, especially brass and zinc-base die castings, based upon these exposure tests and upon experience of producers and users. Drafts of such specifications will be submitted to the cooperating societies through their appropriate committees.

Coatings on Steel:

Electroplated and Hot-Dipped Zinc Coatings.—In the National Bureau of Standards *Research Paper 867*, published in 1936, it was concluded that in industrial locations (New York and Pittsburgh) electroplated and hot-dipped zinc coatings of the same thickness furnished about the same protection against corrosion of the steel. Subsequent observations show that at Sandy Hook, N. J., and Washington, D. C., the hot-dipped steel exhibited, after about $4\frac{1}{2}$ yr., numerous reddish yellow spots, while the zinc-plated steel showed only a uniform dark discoloration. The extensive experience of A.S.T.M. Committee A-5 on Corrosion of Iron and Steel with hot-dipped coatings shows that these fine spots are the result of corrosion of the iron-zinc alloy layer. Continued exposure will be necessary to learn whether there is any appreciable difference between plated and hot-dipped zinc in ability to protect the steel itself against corrosion.

Nickel and Chromium Coatings.—The supplemental tests fully confirmed the earlier conclusion that the total thickness of nickel (plus copper) is the largest single factor in the protective value of the coatings. Under severe conditions, a layer of copper between two layers of nickel has a detrimental effect in coatings with a total thickness up to 0.001 in.

Somewhat thicker coatings of chromium than the customary 0.00002 in. over copper plus nickel on steel increase the protective value in severe locations. The absence with thick chromium deposited on steel of the serious cracking that was observed especially on brass is probably caused by the presence of thicker nickel coatings on the steel than on the brass. There is no apparent reason to limit the maximum thickness of chromium over nickel on steel.

There is very little difference in the protective value of similar coatings on cold-rolled steel, spring steel, and cast iron. On one lot of cold-rolled steel, typical coatings yielded about 10 per cent better protection against corrosion than the average and there was somewhat less tendency for blistering. Further studies that have been planned may show wider variations in the behavior of different kinds of steel.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 212 (1936), also Vol. 38, Part I, p. 250 (1938).

The average protection afforded by bright nickel deposits from four proprietary baths was about the same as that yielded by dull nickel. This and subsequent conclusions in this report regarding bright nickel apply only to the solutions that were available for this study in the spring of 1938 and not necessarily to any solutions developed since that time.

Coatings on Copper and Brass:

Chromium coatings 0.0002 in. thick applied directly to copper on brass, or even to 18 per cent nickel-brass, furnished very little protection against corrosion, even in mild locations.

An increase in the thickness of nickel from 0.00005 in. to 0.001 in. (followed by 0.00002 in. of chromium) produced a continuous increase in protective value. Approximately the same protection is furnished by 0.0002 in. of nickel on brass as by 0.00075 in. of nickel on steel.

Such variations as anodic etching of the brass, the use of a copper strike before the nickel, or the use of air agitation or of a low pH in nickel deposit, had no appreciable effects on the protective value of the coatings. The average protective value of four proprietary bright nickel deposits was about the same as that of dull nickel.

When the thickness of chromium over 0.0002 in. of nickel on brass appreciably exceeds 0.00003 in., there is a decided tendency on exposure for cracks to form and corrosion to occur. For such coatings it may be expedient to specify a maximum as well as a minimum thickness of chromium.

About the same protection was obtained with similar coatings on copper, rolled high- and low-brass, cast high- and low-brass, extruded brass, and cast and rolled 18 per cent nickel-brass.

Coatings on Zinc and Zinc-Base Die-Castings:

The direct applications of chromium coatings 0.0001 in. thick furnished little protection against corrosion, even in mild locations.

Very little protection was afforded by less than 0.0003 in. of nickel. Increasing the thickness of nickel (plus copper) up to 0.002 in. produced a continuous increase in protection. About as much protection was afforded by 0.0005 in. of nickel on zinc as by 0.00075 in. of nickel on steel.

In coatings with a total thickness up to 0.0005 in., a layer of copper increased the tendency for blistering, and failed to increase the protective value above that furnished by the nickel layer that was a part of the composite coating. With a greater total thickness, the copper layer added to the protective value of the nickel. The use of copper may be justified by the fact that it is difficult to produce satisfactory coatings of nickel more than 0.0003 in. thick directly on zinc, on articles of irregular shapes.

There was no marked difference in the behavior of "high-sulfate" nickel coatings and "duplex" nickel coatings of the same total thickness. (Practically, on miscellaneous articles, high-sulfate deposits over 0.0003 in. thick are likely to crack.) There was no consistent difference in the value of plain nickel and bright nickel coatings from four proprietary baths applied at the National Bureau of Standards and from three proprietary baths in commercial plants.

The application of relatively thick chromium coatings (up to 0.00005 in.) over 0.0005 to 0.00075 in. of nickel (plus copper) on zinc showed no excessive cracking (such as was observed over thinner nickel coatings on brass). The coatings on rolled zinc were slightly superior to those on die castings Nos. XXI and XXIII, which latter were about equal.

Effects of Cleaning:

The above conclusions are all based on the appearance after continuous exposure for periods from 8 to 27 months, with no cleaning or other treatment. A few specimens were cleaned after 1 yr. exposure to observe better the condition of the coatings. In general this cleaning improved the appearance, but after a few months any original evidences of corrosion reappeared. The fact that the appearance of plated brass specimens was improved by cleaning more than was that of steel or zinc indicates that any corrosion of brass through pores is more superficial than that of steel or zinc under similar conditions. This partly accounts for the common use of thinner nickel coatings on brass.

Effect of a Grease Film:

The fact that many exposed plated parts of automobiles are frequently treated with grease or wax prompted an investigation in which a thin layer of petrolatum (about 0.000005 in. thick) was applied to a number of the specimens by treating them with a 2 per cent solution of petrolatum in petroleum spirits. The results showed that in general the grease film improved the protection, but that very poor coatings were still inferior and such a treatment is no panacea for poor plating. In a few cases, especially in marine locations, specimens with the grease film actually corroded more rapidly, possibly because they retained salt in the dust adhering to the grease. While grease or wax is usually advantageous for plated coatings exposed outdoors, it should not be counted upon to justify inferior plating.

Respectfully submitted on behalf of the Joint Committee,

W. BLUM,
Chairman.

REPORT OF COMMITTEE C-1

ON

CEMENT

Although Committee C-1 on Cement held two very well-attended meetings during the year, one of which extended through two days, its accomplishments have been disappointingly few. One reason for this was due to the unfortunate inability to secure standard sand for cement testing purposes during a rather extended period. This necessitated holding in abeyance certain contemplated investigations until it became evident that a continuous supply of sand would be available. When assurance of a renewed supply was at hand it was too late to permit of obtaining results for reporting this year. It must be confessed, however, that the committee has shown considerable evidence of its having become a little "overtrained." Having shown rather marked activity for several years, it inevitably happened that a time would arrive which would be marked by a striking break in productiveness. This time occurred during the past year.

Standard Sand:

Going back to the period before the origin of this Society, a standard sand for testing cement was developed by the American Society of Civil Engineers and prepared by the Ottawa Silica Co. of Ottawa, Ill. When the preparation of standards for the purchase and methods of testing cement was given over by that Society to the American Society for Testing Materials, the same sand was specified as prepared by that company. In more recent years one of the standards has been slightly changed in that it does not demand that a sand produced by the above-mentioned company must be used. However, sand from Ottawa, Ill., is required. The Ottawa Silica Co. remained the sole producer of this necessary material.

During the past year a protracted strike exhausted the supply of this company and the supplies of most of the users of the sand. For a while some few were testing cement with sands more or less hastily correlated with the standard Ottawa product. This unforeseen occurrence impressed the committee with the precarious situation which exists as the result of having but one source of supply. It is recognized that remuneration from marketing the sand is small, largely because the demand is small, and that creating more sources will further reduce the attractiveness from a business viewpoint. It is also recognized that the purchasing of cement according to the Society's standards may be thrown into a chaotic state through the failure of one source. The committee is therefore giving this matter considerable thought. In the meantime it is continuing its development of a more truly plastic mortar than that indicated in the Society's Tentative Method of Test for Compressive Strength of Portland-Cement Mortars (C 109 – 37 T).[1] In this study, in addition to making 2-in. cubes of mortar as specified in

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 726 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 476.

Tentative Method C 109, cubes will also be made of the same type of pebble mortar referred to in the 1938 report,[2] and of a synthetic sand graded so as to conform somewhat to the sand now specified in the German standards.

Fineness:

The wide use of the Society's Tentative Method of Test for Fineness of Portland Cement by Means of the Turbidimeter (C 115 – 38 T) brought forward a number of suggested changes. The Working Committee on Fineness (E. W. Reed-Lewis, chairman) has these under consideration. This committee also has originated some studies of the relative water retaining capacity and bleeding of cements. These characteristics of a cement are apparently closely related to its fineness.

In the investigation of bleeding, several test procedures have now been selected for preliminary study; these embrace the use of (1) cement-water grouts, (2) standard sand mortars, and (3) pebble concretes. In each case, the procedure is designed to yield values that may be expressed in terms of relative water capacity of the cement, rather than in terms of the amount of "water gain" or "bleeding" that results from the use of one or more arbitrary cement-water ratios.

With the cooperation of the Working Committee on Plastic Mortar Tests (O. L. Moore, chairman), plans have been made to study these selected test procedures in a group of laboratories, by applying them to five cements that have been chosen to cover a wide range in relative water capacity.

These cooperative studies should afford an indication of the concordance of results obtainable by the several test methods, and it is hoped that they will also throw some light on the question of the practical significance of these results in relation to the design of non-bleeding concretes.

When these preliminary studies of test methods have been accomplished, this Working Committee proposes to direct its attention towards determining some of the major factors that influence the relative water capacities of cements, and to consideration of the scope of further studies that may appear necessary in establishing the relation of relative water capacity to other significant properties of cement and concrete.

Volume Changes:

The committee's vote on the proposed Method of Test for Autoclave Expansion of Portland Cement[3] prepared by the Working Committee on Volume Change and Soundness was favorable and hence it is being submitted to the Society at this meeting for publication as tentative.[4] The publication of this tentative method will enable those interested in making autoclave tests of portland cement to follow a uniform method of test facilitating the direct comparison and evaluation of results obtained by different laboratories.

In order to obtain additional information on different methods of making soundness tests, an outline of the various tests that have been suggested has been prepared and submitted to many of the members of Committee C-1 who make routine tests of cement. A number of laboratories have agreed to cooperate by using several of the different types and brands of cement which they may have occasion to test in connection with their normal routine of cement testing. It is desirable that cements exhibiting as wide a range in characteristics and autoclave expansion as possible be used and particularly that any cements encountered which show autoclave expansions of 1 per cent or more be included. An outline of the tests is appended to this report.

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[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 267 (1938).

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 297 (1938).

[4] The proposed tentative method was not accepted by the Society at the annual meeting, see Summary of Proceedings, p. 25.—ED.

The Working Committee has under consideration the study of existing data on shrinkage tests of cement with particular reference to the factors which influence shrinkage and the rate and degree of shrinkage encountered with different types of cement. One of the objects of this study will be to develop, if possible, a convenient method of test for evaluating the shrinkage characteristics of different types of cements when tested alone and in mortar and concrete.

Time of Set:

It is realized that the present methods for time of set are crude and that these tests reveal only a small part of the desired information about the early stiffening and hardening of cements. Furthermore, cooperative tests, particularly the one conducted recently by the Cement Reference Laboratory, show that the variations in the results of setting time tests are greater than are found in any other physical test.

The committee has given thought to other types of tests for early stiffening and hardening, particularly compression tests conducted on mortars at very early ages (beginning at the time of initial set). One laboratory has done considerable work toward developing this type of test and arrived at results which appeared very promising. Comparative tests among two laboratories, however, showed that additional refinements must be made.

It seems to be a foregone conclusion that any test for time of setting, in order to give dependable results, will require even closer control of conditions and manipulations than most of the other physical tests, because of the fact that the physical properties of the cement are changing very rapidly at the time the test is performed.

At the spring meeting of the committee, the elimination of the requirement for final time of setting from the Standard Specifications for High-Early-Strength Portland Cement (C 74 - 38)[5] was approved for reference to letter ballot. The committee accordingly recommends the following revision in these specifications and asks for the necessary nine-tenths vote at the annual meeting in order that this modification may be referred to letter ballot of the Society:

Section 3.—Change to read as follows by the omission of the sentence in brackets:

3. The cement shall not develop initial set in less than 45 min. when the Vicat needle is used or in less than 60 min. when the Gillmore needle is used. [Final set shall be attained within 10 hr.]

Chemical Analysis:

A report of the Working Committee on Methods of Chemical Analysis (W. C. Hanna, chairman) for cements is appended hereto. The report speaks for itself in indicating the marked activity of this Working Committee. As a result of its recommendations, the Society is being asked at this time to accept as tentative two alternate methods for the determination of "free lime" in portland cement and a method covering the order and manner of reporting results of chemical determinations.

Cement Standards:

As mentioned above, the committee is recommending the deletion of the requirement for final time of setting from the Standard Specifications for High-Early-Strength Portland Cement (C 74 -38).[5] Since these specifications contain a 24-hr. strength requirement, it has been felt for some time that the fact that any cement which would have hardened sufficiently at 24 hr. to pass the strength requirement was sufficient evidence that it had a normal final set and hence the test for final set was not necessary. After much discussion this change is recommended.

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[5] 1938 Supplement to Book of A.S.T.M. Standards, p. 97.

The Working Committees on Low Heat Cements (G. A. Beckett, chairman) and on Blended Cements (R. E. Roscoe, chairman) have continued their work in developing standards but are not yet in a position to present any for approval.

No changes are offered in the Standard Specifications for Portland Cement (C 9 – 38) nor in the Tentative Specifications and Tests for Masonry Cements (C 91 – 38 T).

The specific gravity determination long ago dropped from the portland cement specifications is now being used in studies of concrete. On that account the committee is submitting a revision of the former method for determining the specific gravity of cement.[6] The committee recommends this method for immediate inclusion in the Standard Methods of Sampling and Testing Portland Cement (C 77 – 38)[7] and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that this recommendation may be referred to letter ballot of the Society.

Cement Reference Laboratory:

The sixth tour of inspection of cement testing laboratories is now well under way and should be about completed during this calendar year. Close to 300 laboratories will have been visited when the tour is over. In the report of the committee appended hereto further information regarding its work is given, as well as a tabulation of results obtained from 161 laboratories which cooperated in carrying out physical tests and chemical analyses of a sample of cement according to the Society's standard procedure.

The results of this have been before the committee for some time and have been the subject of much discussion. It is believed that such cooperative work is of sufficient value to justify its continuation. Accordingly, annually two samples will be distributed to all laboratories which may be interested. One of the samples will be for chemical analysis alone while about six months after the distribution of this sample a second one will be distributed for both chemical analysis and physical testing.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Method of Test for Autoclave Expansion of Portland Cement.[a]	52	12	2
II. REVISION OF TENTATIVE STANDARD			
Method of Chemical Analysis of Portland Cement (C 114 – 38 T), new alternate methods for determining free calcium oxide in cement	52	0	16
III. REVISIONS OF STANDARDS			
Specifications for High-Early-Strength Portland Cement (C 74 – 38), immediate deletion[b] of final setting time requirement	45	12	11
Methods of Sampling and Testing Portland Cement (C 77 – 38), immediate addition:			
Test for specific gravity	61	0	7
Order and manner of reporting chemical determinations	55	1	11

[a] The classified vote on the proposed Tentative Method of Test for Autoclave Expansion of Portland Cement was as follows: Affirmative: 30 producers, 15 consumers, 7 general interests; negative: 4 producers, 3 consumers, 5 general interests. The recommendation for publication as tentative of this method failed of approval at the annual meeting of the Society, see Summary of Proceedings, p. 25.

[b] The classified vote on the adoption of the proposed revision of the Standard Specifications for High-Early-Strength Portland Cement (C 74 – 38) was as follows: Affirmative: 29 producers, 12 consumers, 4 general interests; negative: 3 producers, 4 consumers, 5 general interests.

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[6] This method was adopted as standard by the Society and incorporated in the Standard Methods of Sampling and Physical Testing of Portland Cement (C 77 – 39), 1939 Book of A.S.T.M. Standards, Part II.

[7] 1937 and 1938 Supplements to Book of A.S.T.M. Standards.

Addition to Cements:

It will be noted from the appended report of the Committee on Tests of Additions to Cement (C. H. Scholer, chairman) that as a result of the revision of the Society's standard for normal portland cement by which the addition, subject to calcination, of materials other than calcium sulfate and/or water is permissible under certain conditions, Committee C-1 through the Cement Reference Laboratory is carrying out tests prescribed by the Committee on Additions on a material known as TDA, produced by the Dewey & Almy Chemical Co. of Cambridge, Mass. Tests previously carried out on this material in high-early-strength cements showed it not to be harmful.

RECOMMENDATIONS AFFECTING STANDARDS

The recommendations appearing in this report have been submitted to letter ballot of the committee, which consists of 83 voting members; 68 members returned their ballots, with the results shown in Table I.

This report has been submitted to letter ballot of the committee, which consists of 83 voting members; 77 members returned their ballots, of whom 71 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

P. H. BATES,
Chairman.

L. W. WALTER,
Secretary.

OUTLINE OF COOPERATIVE STUDIES OF VARIOUS TYPES OF SOUNDNESS TESTS

SPONSORED BY WORKING COMMITTEE ON VOLUME CHANGE AND SOUNDNESS

PROCEDURE FOR MAKING TESTS

Preparation of Test Specimens:

Mix a neat cement paste or a 1 to 3 standard sand mortar of normal consistency in accordance with the procedure described in Sections 25 to 28 of the Standard Methods of Sampling and Testing Portland Cement (A.S.T.M. Designation: C 77 – 37) of the American Society for Testing Materials.[1] Use a batch of sufficient size to make *all neat cement* or *all mortar specimens* indicated in the outline given in the accompanying table from the *same batch.*

Mold the 1 by 1 by 11¼-in. neat bars in group 1 in accordance with the proposed Tentative Method of Test for Autoclave Expansion of Portland Cement.[2]

Group	Kind of Specimen	Water Content (Consistency)	Curing	Exposure	Type of Observation	Number of Specimens		
						From Same Batch	Number of Batches	Total Each Cement
1 1A[d]	1 by 1 by 11¼-in. bar of neat cement	A.S.T.M. Normal	1 day Moist Air	5 hr. Autoclave (3 hr. at 420 F.)	Length change	1	1	1
2	Same as Group 1, except for method of molding specimen[a].							
3	Neat cement pat	A.S.T.M. Normal	1 day Moist Air	5 hr. Autoclave (3 hr. at 420 F.)[b]	Unsoundness[c]	1		1
4	Neat cement pat	A.S.T.M. Normal	1 day Moist Air	Standard A.S.T.M. Soundness Test	Unsoundness	1		1
5	Neat briquet	A.S.T.M. Normal	1 day Moist Air	Moist Room	Test for strength at 30 hr.	3		3
6	Neat briquet	A.S.T.M. Normal	1 day Moist Air	5 hr. Autoclave (3 hr. at 420 F.)	Test for strength at 30 hr.	3		3
7	1–3 standard sand briquet	A.S.T.M. Normal	1 day Moist Air	Moist Room	Test for strength at 30 hr.	3	1	3
8	1–3 standard sand briquet	A.S.T.M. Normal	1 day Moist Air	5 hr. Autoclave (3 hr. at 420 F.)	Test for strength at 30 hr.	3		3
9	NOTE.—It is suggested that laboratories which have the Le Chatelier equipment make the Le Chatelier test following their normal procedure.							

[a] In making specimens in this group use the revised method of molding described in the accompanying procedure.

[b] Remove pat from glass before placing in autoclave; the glass on which pat is molded should be oiled with oil such as is used for briquet molds in order to facilitate removal of pat.

[c] By observation of cracking, checking, warping, etc., dry and after wetting, using a reading glass.

[d] If convenient also make occasional tests on bars *cured moist for 14 days* before autoclaving.

In molding the bars in group 2, fill the mold in one or two layers and compact each layer with thumb or forefinger sufficiently to obtain a uniform specimen, strike off excess paste and smooth surface with a few strokes of a trowel. Keep a record of the number of tampings required to satisfactorily mold the specimen and note whether filling in more than one layer is necessary.

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[1] 1937 Supplement to Book of A.S.T.M. Standards, p. 54.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 297 (1938).

In molding the soundness pats for the autoclave test (group 3), follow the normal procedure but after molding use a circular cooky cutter ($2\frac{3}{4}$ in. in diameter) and cut off the beveled edge of the pat so as to produce a pat with sharp-cornered thickened edges.

Mold the neat cement briquets and 1 to 3 standard sand briquets (groups 5 to 8) in accordance with the A.S.T.M. Standard Method C 77.[1]

Curing and Testing of Specimens:

Cure specimens in all groups except group 1A for 24 hr. in molds in a moist closet and test as follows:

Groups 1 and 2.—Test the specimens in accordance with the Proposed Tentative Method of Test for Autoclave Expansion of Portland Cement.[2]

Group 3.—Test the pats by subjecting them to the autoclave treatment as in group 1 and make visual observations for unsoundness as manifested by change in volume which causes distortion, cracking, checking, swelling, or disintegration. Examine pats, both when dry and wet, with a reading glass.

Group 4.—Test the specimens for soundness in accordance with the procedure described in Sections 32 to 35 of the A.S.T.M. Standard Method C 77.[1]

Groups 5 and 7.—Test the briquets for tensile strength at age of 30 hr. when autoclaved briquets are tested.

Groups 6 and 8.—Test the briquets at age of 24 hr. by subjecting them to the 5-hr. autoclave treatment used in group 1. Measure the width and thickness of the briquets at the waist line with a micrometer, noting whether specimens expand so that they cannot be placed in the briquet machine, and then test in tension at age of 30 hr. Record strength and note change in appearance due to autoclave treatment such as cracking, checking, or disintegration and any noticeable change in volume.

REPORT OF WORKING COMMITTEE ON METHODS OF CHEMICAL ANALYSIS

Methods for Free Calcium Oxide (Free Lime):

The progress report published in the ASTM Bulletin for October, 1938, included the results obtained by 37 laboratories with 8 different methods for the determination of free calcium oxide in portland cement and clinker.[1] The methods were described in full detail in the progress report of February 24, 1938. The brief outline given below summarizes these methods.

Methods Ia, Ib, IIa, IIb, IIIa, and IIIb are modifications of Emley's glycerol-ethanol method. Method Ia is the modification developed by Lerch and Bogue.[2] Method Ib is the same as method Ia except for the kind of glycerol.

The use of U.S.P. or "chemically pure" glycerol containing water up to 5 per cent is allowed in the "a" methods, while nearly anhydrous glycerol is required in the "b" methods. For any pair of methods as Ia and Ib, IIa and IIb, or IIIa and IIIb, the two methods are the same except for glycerol.

Anhydrous barium chloride is used as an accelerator in methods IIa and IIb. It was suggested by H. R. Brandenburg of the Cowell Portland Cement Co.[3]

The use of dried sodium chloride as an accelerator as in methods IIIa and IIIb was suggested by T. A. Hicks of Universal Atlas Cement Co. in a private communication.

Four different end points were used in these six methods, as follows:

(1) When the pink color of phenolphthalein does not reappear after 1 hr. of boiling.

(2) When after 2 hr. of boiling the content of free lime does not increase by more than 0.05 per cent.

(3) When the pink color of phenolphthalein does not reappear after 30 min. of boiling.

(4) When after 1 hr. of boiling the content of free lime does not increase by more than 0.05 per cent.

The end points (1) and (2) are for methods Ia and Ib. It is convenient to use the two end points on the same portion of sample but they are independent of each other, and (2) does not necessarily follow (1) in all cases. The same thing can be said of the end points (3) and (4) which are used in methods IIa, IIb, IIIa, and IIIb.

Methods IV and V are different modifications of the ethylene glycol method.

In method IV[4] a solution of ethylene glycol and methanol is used as solvent. A mixture of the sample and the solvent is refluxed for 30 min. and then filtered. The filtrate is titrated with standard acid.

In method V[5] a mixture of the sample and ethylene glycol is shaken at 65 to 70 C. for 30 min. and then filtered. The filtrate is titrated with standard acid. Equipment for shaking and for temperature control is required.

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[1] W. C. Hanna, T. A. Hicks, and G. A. Saeger, "Cooperative Study of Methods of Determining Free Lime in Portland Cement and Clinker," published in ASTM Bulletin, No. 94, October, 1938, p. 47.

[2] *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 2, No. 3, July 15, 1930, p. 296.

[3] *Rock Products*, Vol. 34, No. 6, March 14, 1931.

[4] Method developed by S. Rordam, Director of Research, Cowham System Plants, *Rock Products*, Vol. 40, No. 8, August, 1937, p. 72.

[5] Method developed by D R. MacPherson and L. R. Forbrich. *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 9, October, 1937, p. 451.

Since the publication of the data, 14 of the cooperating laboratories have reported on their opinions of the methods as obtained from a study of all the data. It may not be correct to assume that all of the other 23 laboratories are adhering to their original opinions as expressed in Table IV in the report published in October.[1] However, if it is assumed that they are, a revision of Table IV would show by how many laboratories each method was preferred, thus:

Method	Number of Laboratories For Preferred Method	For Alternate Method
Ia	9	0
Ib	0	0
IIa	6	9
IIb	0	1
IIIa	2	8
IIIb	1	1
IV	6	6
V	1	2

The revised table would also show that end points (1) and (3) were favored by 4 laboratories, while end points (2) and (4) were favored by 8.

In the study of the data, the Working Committee has been assisted greatly by those who studied the results and made suggestions but the formation of conclusions has been handicapped by two facts. First, no one of the methods is favored by a majority of those who have tried them.

The other fact is that there is no method for free calcium oxide which is known beyond reasonable doubt to give absolutely accurate results and which can be used as an infallible guide by which all other methods are judged. It seems that in the absence of such a method there is a tendency to judge the accuracy of any method by comparing it with method Ia which is the best known and most established method in this country. We believe that, for practical purposes, this tendency is justified until another method is proved to be superior in accuracy.

It has been suggested that the study be continued before any recommendations are made. A great deal of work has been done on this problem and the Working Committee feels that there would be little to be gained by such further studies unless a new method should be presented that promises to be better than those already tried.

The Working Committee has decided to recommend method Ia and method IIa–IIIa as alternate procedures for determining free calcium oxide in Portland cement and clinker. Method Ia, which is the preferred procedure, is practically the same method as developed by Messrs. Bogue and Lerch, except for the end point. End points (1) and (3) have been in general use, but end points (2) and (4), the idea of which was conceived by the Working Committee, found greater favor among those who tried them. The latter end points are specified in the recommended methods, end point (2) for the preferred method and end point (4) for the alternate method. Method IIa–IIIa is a combination of method IIa and method IIIa and gives the operator his choice of barium chloride and sodium chloride as accelerator. These methods,[6] rewritten in A.S.T.M. style, are recommended for publication as tentative, to be included in the present Tentative Methods of Chemical Analysis of Portland Cement (A.S.T.M. Designation: C 114) of the American Society for Testing Materials.[7]

The Working Committee gave serious thought to the possibility of recommending method IV as a second alternate method but it was decided that it was not advisable to recommend too many alternate methods when one alternate method in the form of method IIa–IIIa would satisfy the requirements in most cases for a quick method of test. On the basis of averages and probable errors, as compared with method Ia, method IV seems to have a tendency to give high results with clinker low in free lime but, as a whole, it compares favorably with methods IIa and IIIa. The A.S.T.M. methods are primarily for the purpose of acceptance tests. Any laboratory would be justified in using method IV for obtaining information which is not intended for the acceptance or rejection of cement.

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[6] These methods were accepted as tentative by the Society and appear in the Tentative Methods of Chemical Analysis of Portland Cement (C 114 - 39 T), see 1939 Book of A.S.T.M. Standards, Part II.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 738 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 468.

Method V did not find very much favor among those cooperating laboratories that were able to obtain the necessary apparatus. The expensive equipment required is probably the chief objection to the method. Some of the operators also had considerable trouble in getting rapid and clear filtration, which was possibly due to lack of experience with the method. It is possible for an experienced operator to obtain results that check fairly well with results by method Ia.

On the average, method Ia requires about 7 hr. for a determination while method IIa–IIIa requires about 3 hr. When only one or two determinations are to be run, method IV or method V may be used to good advantage as each requires only 1 hr. or less per determination, but these procedures require constant attention. When a larger number of determinations are to be made in one day, most operators will find it more satisfactory to use method IIa–IIIa because it does not require constant attention and they can attend to other work at the same time.

Anhydrous or nearly anhydrous glycerol was required for methods Ib, IIb, and IIIb and directions were given for its preparation from ordinary glycerol. Two of the cooperating laboratories in this country reported the purchase of anhydrous glycerol but the Working Committee was unable to locate a source of anhydrous glycerol in this country.

One of these two laboratories obtained some glycerol which was labelled "c.p. anhydrous special glycerol." Several months after its use, its specific gravity was determined and the water content was calculated to be 1.6 per cent. Complete information about this glycerol could not be obtained from the dealer.

The other laboratory used glycerol which a well-known manufacturer markets as "special-absolute-pure glycerine, c.p." at a high price. Tests of the material indicated that it contains 5 per cent of water. This has been taken up with the manufacturer but as yet a reply has not been received.

It seems that some dealers of laboratory supplies have the impression that "chemically pure" glycerol is 100 per cent glycerol. It is natural but erroneous. It is obvious that water is not considered to be an impurity by manufacturers. In the method a note has accordingly been included calling attention to the possible presence of water. Five per cent of water is allowed but it is necessary to test the glycerol in order to be sure that this limit is not exceeded.

The work of the investigation shows that when a salt is not used to accelerate the solution of free calcium oxide in the glycerol-ethanol method, the result is not affected by water whose content in the solvent may be as great as 0.8 per cent. On the other hand, when a salt is used as accelerator, there may be an appreciable decomposition of sample which is increased by the presence of water. However, the method, in which such an accelerator may be used, can be employed only as an alternate method and is subject to a check by the preferred method in case of dispute. The removal of water from glycerol would mean additional expense. For these reasons anhydrous glycerol is not specified either in the preferred method or in the alternate method. A note has been inserted calling attention to the tendency of the alternate method (method B) to give higher results than the preferred method (method A), and to the value of occasionally checking results of the alternate method by the preferred method.

At the last meeting of Committee C-1, one member suggested that the report on the investigation of methods for the determination of free calcium oxide should include analyses of the samples. The usual analyses and calculated compounds of the samples used in the investigation are as follows:

Components, per cent	Sample[a]			
	N	O	Q	R
SiO_2	22.7	22.5	21.1	21.0
Al_2O_3	5.6	5.4	5.1	4.9
Fe_2O_3	2.3	2.1	2.3	5.7
CaO	63.9	63.7	62.8	62.1
MgO	4.1	4.0	3.8	2.8
SO_3	0.2	0.3	1.9	1.7
Loss on ignition	0.1	0.4	1.7	1.0
CO_2	0.0	..	0.3	..
$3CaO \cdot SiO_2$	46	48	52	47
$2CaO \cdot SiO_2$	31	28	22	24
$3CaO \cdot Al_2O_3$	11	11	10	3
$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	7	7	7	17

[a] Sample P is a mixture of 54 per cent of sample N and 46 per cent of sample O.

Investigation of Methods for Phosphorus Pentoxide:

Three methods for the determination of phosphorus pentoxide have been tested at different times. They are known to the Working Committee as methods III, IV and V (for P_2O_5).

The results with method III were presented in the progress report of January 8, 1937, and the method was published as tentative in Method C 114 – 38 T[7] (Sections 1 and 2). A search was initiated for a quicker procedure which could be used as an alternate method. Results with method IV, proposed by W. A. Van Winkle, Kansas State College of Agriculture and Applied Science, showed the need of improvement. After a large number of tests O. A. Ellingson, Universal Atlas Cement Co., worked out a modification. This new modification (method V) has been tested. The method proved to be a quick test procedure and it gave good results in most of the cases but, as some of the operators reported difficulty with sample S which is low in phosphorus pentoxide, Messrs. Van Winkle and Ellingson are making additional studies, especially with the idea of making the method work better with cement low in phosphorus pentoxide. Until their results are available, the Working Committee is not prepared to make a recommendation in regard to a tentative alternate method for phosphorus pentoxide. The continuation as tentative of the procedures described in Sections 1 and 2 of Method C 114 – 38 T[7] is accordingly recommended.

Methods for Manganic Oxide:

The tentative alternate method for manganic oxide (C 114 – 38 T, Sections 5 and 6) has been in effect less than one year. It is recommended that both this method and the tentative standard method for manganic oxide (C 114 – 38 T, Sections 3 and 4) be continued as tentative.

Investigation of Methods for Sodium Oxide and Potassium Oxide:

A method for sodium oxide and potassium oxide had been suggested by F. H. Jackson, Senior Engineer of Tests, U. S. Bureau of Public Roads. Members of the Working Committee have tried the method in their laboratories and have found it to be satisfactory and also quicker than the present tentative method (C 114 – 38 T, Sections 7 and 8). A modification which may be still simpler and quicker is now being studied. At this time the committee is not able to make any recommendation in regard to the tentative methods for sodium oxide, potassium oxide, and water soluble alkali (C 114 - 38 T, Sections 7, 8, and 9) except that they be continued as tentative.

Investigation of Quick Methods for Silicon Dioxide, Calcium Oxide, and Magnesium Oxide:

A tentative program has been worked out for the investigation of quick methods for determining silicon dioxide, calcium oxide, and magnesium oxide, the purpose of which is to find shorter methods which can be recommended for adoption as alternate methods for these components. The Working Committee will be glad to receive suggestions in regard to this work.

Uniform Method of Reporting Analyses:

It was stated in a progress report that analyses were reported in many different methods and that it had been suggested that our Working Committee should recommend a uniform method. A recommended order of components is given below. It is in the main patterned after the order recommended in U. S. Geological Survey *Bulletin No. 700*, "The Analysis of Silicate and Carbonate Rocks" (W. F. Hillebrand). There are a few differences which are required by the nature of portland cement and the customs of cement analysts.

RECOMMENDED ORDER FOR REPORTING CEMENT ANALYSIS

Major Components:	
SiO_2	Silicon dioxide (Silica)
Al_2O_3	Aluminum oxide (Alumina)
Fe_2O_3	Ferric oxide
CaO	Calcium oxide (Lime)
MgO	Magnesium oxide (Magnesia)
SO_3	Sulfur trioxide (Sulfuric anhydride)
Loss on ignition.	
Minor Components:	
FeO	Ferrous oxide
Na_2O	Sodium oxide (Soda)
K_2O	Potassium oxide (Potash)
H_2O	Hydrogen oxide (Water)
CO_2	Carbon dioxide (Carbonic anhydride)
TiO_2	Titanium dioxide (Titania)
P_2O_5	Phosphorus pentoxide (Phosphoric anhydride)
Cl	Chlorine
S	Sulfide sulfur
Mn_2O_3	Manganic oxide
Separate Determinations:	
Insoluble residue	
Free CaO	Free calcium oxide (Free lime)

The matter of proper names for the various components has also been considered. There are common names for some of the components (such as silica and lime) which have been in general use a long time, even among chemists. It is the opinion of the Working Committee that scientific names should be used, especially in publications and reports. It has been the practice of the Working Committee in recent years to try to avoid the use of common names but they are included here in parentheses as information.

The number of figures to use in reporting analyses has also received consideration. It is the universal custom of analysts to express results to two decimal places. It is unfortunate in the field of cement analysis because the use of two decimal places gives the analysis an apparent degree of accuracy which is, in fact, not usually obtained. When several laboratories make a determination, as in the cooperative series sponsored by the Working Committee, it is often useful to give the results to two decimal places in order to study the degree of variation. For example, two analysts may obtain 0.05 per cent and 0.14 per cent of something in a sample and their difference would not be shown if the results were reported as 0.1 per cent. However, as far as the acceptance of cement is concerned, one decimal place is sufficient. For some years it has been the practice of the National Bureau of Standards to report the results of cement analysis to one decimal place and the calculated compounds ($3CaO \cdot SiO_2$, $3CaO \cdot Al_2O_3$, etc.) in round numbers. This practice is recommended by the Working Committee.[8]

If these suggestions are sound, the A.S.T.M. standard methods and specifications should be revised so that (1) the methods for chemical analysis are arranged according to the recommended order of components, (2) scientific names are substituted for common names, and (3) the chemical limits and permissible variations are expressed to one decimal place.

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[8] This recommended order for reporting analysis was accepted and appears in the Standard Methods of Chemical Analysis of Portland Cement (C 114 - 39), see 1939 Book of A.S.T.M. Standards, Part II.

Balances and Weights:

The question has been raised as to whether cement analysts are using balances and weights of the right types and are checking them often enough. The committee believes it well to call attention to the existence of Section 18 of Standard Methods of Sampling and Testing Portland Cement (C 77 – 37)[9] which specifies the types of balances and weights to be used in chemical determinations.

National Bureau of Standards *Circular No. 3*, "Design and Test of Standards of Mass," which is mentioned in Section 18 (*e*) is now out of print and the Bureau is considering a revision of the circular. National Bureau of Standards *Handbook M85*, mentioned in a footnote to Section 18 (*d*), has been superseded by *Handbook H22* (1937). This handbook may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The price is 50 cents a copy. When the revised circular on standards of mass is published, the Working Committee will consider the possibility of revising Section 18 or at least bringing it up to date.

Cement Reference Laboratory Comparative Sample No. 2:

The tests on portland cement Comparative Sample No. 2 of the Cement Reference Laboratory are covered by a report[10] issued by the National Bureau of Standards under the date of January 6, 1939. Results were submitted by 161 laboratories and 134 of them made chemical analyses which are given in Table I of the report in the Appendix. Attention is called to the great amount of variation in the analyses. Methods of chemical analysis cannot be made foolproof and it appears from these results that the chemical analysis of cement should be undertaken only by analysts who are careful and experienced in this kind of work.

It is also to be noted that the number of laboratories departing from the prescribed methods in various ways is great. Some of the deviations are doubtless due to a desire to save time or avoid the purchase of requisite supplies, but some deviations cannot be explained except as a disregard or a careless reading of the directions. When a number of analysts undertake to assist in any important cooperative program, they should follow the instructions faithfully to the best of their ability; otherwise much of the value of their work may be lost.

It is not enough to provide methods which, if used properly, will give accurate results. There is need, as shown by these tests of the comparative sample, for a sample of portland cement with an accurate analysis certified by a recognized authority. It would be a great help to cement analysts in checking their work. Some years ago the Working Committee discussed with Dr. G. E. F. Lundell the possibility of the National Bureau of Standards issuing a standard sample of portland cement with a certified analysis. He seemed to be favorable to the idea but there was a special problem in this case because of the tendency of cement to absorb moisture and carbon dioxide from the air. The possibility of putting this cement up in small ampules instead of large bottles was considered. In view of the need for such a standard sample, it is suggested that the officers of Committee C-1 take up this matter with Dr. Lundell and the Bureau.

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[9] 1937 Supplement to Book of A.S.T.M. Standards, p. 54.

[10] A brief summary of the detailed report appears in the Appendix on p. 323.

Acknowledgment:

The thanks of the A.S.T.M. and the Working Committee are due many who have assisted in these cooperative studies in various ways, especially those who for a third time cooperated in the investigation of methods for phosphorus pentoxide.

Respectfully submitted on behalf of the Working Committee,

W. C. HANNA,
Chairman.

REPORT OF SUBCOMMITTEE ON CEMENT REFERENCE LABORATORY

(Period July 1, 1938 to June 30, 1939)

Announcement was made of the plans for the sixth inspection tour which is now in progress among cement laboratories. Requests for inspection were received from 280 laboratories. Seven requests were already recorded when the tour was announced. The 290 laboratories thus far involved are classified as follows:

Cement producers	120
Commercial testing	69
State highway	56
Schools	20
Municipal	9
Miscellaneous	16
Total	290

The numbers of laboratories requesting inspection in the five preceding tours were respectively 208, 265, 224, 229, and 309.

Inspections at 146 laboratories have been made. The field work is practically completed in the eastern, southern, and southwestern states.

The U. S. Bureau of Public Roads and the Public Works Administration have continued to require the Cement Reference Laboratory inspection at laboratories involved in testing cement for certain government projects.

Consideration has been given to increasing the attention given to such items as small flow tables, cube molds, testing of masonry cements, and preparation of plastic mortar cubes. The calibration of compression testing machines has also received additional thought. The electrical division of the National Bureau of Standards has studied one of the proposals discussed at the November meeting of Committee C-1: namely, the field testing of microammeters used with the Wagner turbidimeter. As a result of this study, equipment suitable for field tests of microammeters has been finally decided upon and specifications for the purchase of the necessary assemblies of field equipment have been prepared.

Miscellaneous work has included the usual routine correspondence and records, furnishing equipment information, cooperating in tests of substitute sands during the scarcity of the standard 20–30 Ottawa sand, testing miscellaneous cement equipment received at the laboratory, and endeavoring to secure more uniformity in turbidimeter details.

The last of the 161 laboratories which participated in the tests of Comparative Sample No. 2 submitted their reports in the late summer. The data were tabulated and summarized by the Reference Laboratory into a report which was distributed by the National Bureau of Standards to the laboratories which had submitted data. Copies of the report were also distributed to those members of Committee C-1 who had not participated in the tests. Thus, each member of the committee has had an opportunity to review the results of these comparative tests. Studies not included in the report were also made in the endeavor to learn more about the possible effect of some variables. Some of these additional studies were made the subject of discussion at the spring meeting of Committee C-1. A compact summary of the results of the tests of Comparative Sample No. 2 is appended to this report.

Assistance was given to the Subcommittee on Tests of Additions to Cements in abstracting the lengthy complete report which the Reference Laboratory had submitted to that subcommittee at the end of the first series of tests of TDA in high-early-strength cements. Work was started on the second series of tests of TDA, that material now being tested as an addition during the grinding of normal portland cement.

Respectfully submitted on behalf of the subcommittee,

G. E. WARREN,
Chairman.

APPENDIX

RESULTS OF TESTS ON COMPARATIVE SAMPLE NO. 2 OF THE CEMENT REFERENCE LABORATORY

Because of the interest in the results of the tests on the first general comparative sample of the Cement Reference Laboratory, a second sample was prepared and distributed early in 1938 under the designation of Comparative Sample No. 2. The results of sample No. 1[1] were helpful in planning the tests of sample No. 2, but the scope of the work for sample No. 2 was made greater than for the earlier sample, which had been distributed to only 50 laboratories. The second sample was sent to all laboratories which had taken part in recent inspection work of the Reference Laboratory and which desired to participate in the tests. The tests on sample No. 1 had consisted of the more commonly made physical determinations and a study of the agreement in results when certain tests were made on three different days. The program for sample No. 2 included the standard physical tests; autoclave expansion tests; turbidimeter fineness, and compressive strength determinations; and chemical analyses, the latter including the determinations of some of the minor constituents.

Each of the laboratories participating in the tests of sample No. 2 has received a copy of a lengthy report[2] wherein are presented many details and comparisons. The more compact brief summary herein presented is intended to offer the essence of the larger report in a convenient form for the information of other laboratories.

PARTICIPANTS

The names and locations of the 161 laboratories which submitted test results are shown in the detailed report mentioned above. It is desired to emphasize that neither the alphabetical order of names in the detailed report, nor the order of interest grouping herein, correspond in any way with the order of laboratory identification numbers in the tabulations in the larger report.

DISTRIBUTION OF PARTICIPATING LABORATORIES ACCORDING TO INTERESTS

Interest	Laboratories
Commercial testing	28
Government	8
State highway	41
Miscellaneous	5
Municipal	7
Cement producers	66
Schools	6
Total	161

SAMPLE AND INSTRUCTIONS

The sample was carefully selected and prepared so as to secure uniformity of material throughout. After the final mixing, the dry cement was placed in metal containers and the lids thereof soldered in place. A study of certain of the results indicates that satisfactory uniformity of material was obtained. Each of the participating laboratories received instruction sheets and report forms. The instructions, in so far as possible, made use of existing A.S.T.M. standards. The methods used are mentioned in the following discussion of the test results.

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[1] "Report on Cooperative Tests of Portland Cement Comparative Sample C.R.L. No. 1, ASTM BULLETIN, No. 89, December, 1937, p. 19.

[2] Those laboratories which may desire to study the details of the more complete report may secure a copy, so long as the supply thereof is available, by addressing the Cement Reference Laboratory at the National Bureau of Standards, Washington, D. C.

TEST RESULTS

General:

When calculating the averages, deviations, etc., for any certain test, all of the reported values were used except as otherwise indicated in the tables. Not all of the laboratories made all of the tests outlined, and a few laboratories submitted results too late for inclusion in the summaries of some tests.

It should be kept in mind, particularly when studying the results of the chemical analyses, that the averages are presented for the convenience of readers in making the usual comparisons, and that emphasis is placed on the fact that such averages are not submitted as necessarily the most probably correct values. The maximum and minimum values are presented with full realization that some of the wide departures from average values may be the result of errors in calculating or reporting results. Graphical and tabular presentations of frequency distributions of results are given in this report to afford more complete information as to agreement between laboratories than is furnished by brief statements of average, maximum, and minimum values.

Chemical Determinations:

The methods as prescribed for certain of the determinations were as follows:

(*a*) Silicon oxide, ferric oxide, aluminum oxide, calcium oxide, magnesium oxide, sulfuric anhydride, loss on ignition, insoluble residue, determined in accordance with the chemical determinations described in the Standard Methods of Sampling and Testing Portland Cement (C 77 - 37).[3]

(*b*) Phosphorus, manganese, sodium and potassium oxides, and water-soluble alkali determined in accordance with the Tentative Methods of Chemical Analysis of Portland Cement (C 114 - 38 T).[4]

The results of chemical determinations are presented in Table I. Some laboratories reported deviations from prescribed methods for certain determinations.

During the summarizing of the chemical data there arose a number of questions which were brought to the attention of parties engaged in studying methods of analyzing cement. Particularly has attention been invited to the matter of greater uniformity in the manner of reporting cement analyses and also to the question of how many decimal places are warranted in reporting the various determinations. When preparing the tables, the chemical results were tabulated to two decimals, since that was the method of reporting used by nearly all of the participating laboratories. However, it is not to be

TABLE I.—CHEMICAL ANALYSES.

Constituent	Average, per cent	Maximum, per cent	Minimum, per cent	Number of Laboratories Included in Average
SiO_2	21.22	22.15	18.52	124
Fe_2O_3	2.09	6.42	0.16	122
Al_2O_3	5.83	8.24	2.02	122
CaO	64.43	66.50	61.66	124
MgO	3.08	7.26	1.43	133
SO_3	1.86	2.17	1.69	133
Ignition loss	1.09	2.91	0.38	133
Insoluble residue	0.17	1.60	0.02	130
Na_2O	0.27	0.60	0.08	52
K_2O	0.25	0.51	0.04	52
Mn_2O_3	0.08	0.55	trace	70
P_2O_5	0.20	0.59	0.07	67
TiO_2	—	0.18	trace	3
Free CaO	—	1.25	0.86	8
Water soluble alkali Na_2O	—	0.52[a]	0.01[a]	13
Soluble Na_2O	—	0.04	0.01	4
Soluble K_2O	—	0.07	0.04	4

[a] Nine results varied from 0.06 to 0.08 per cent, both inclusive.

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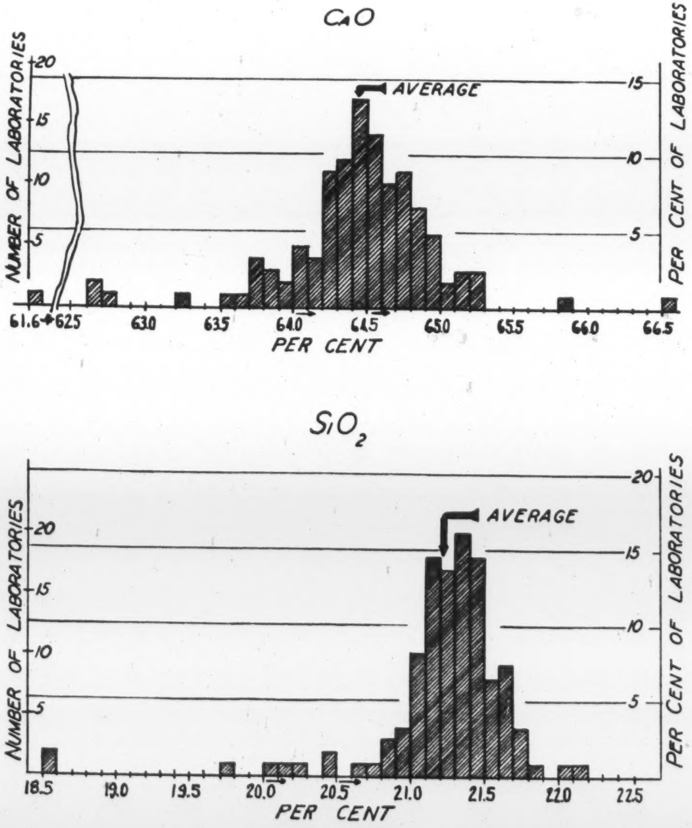
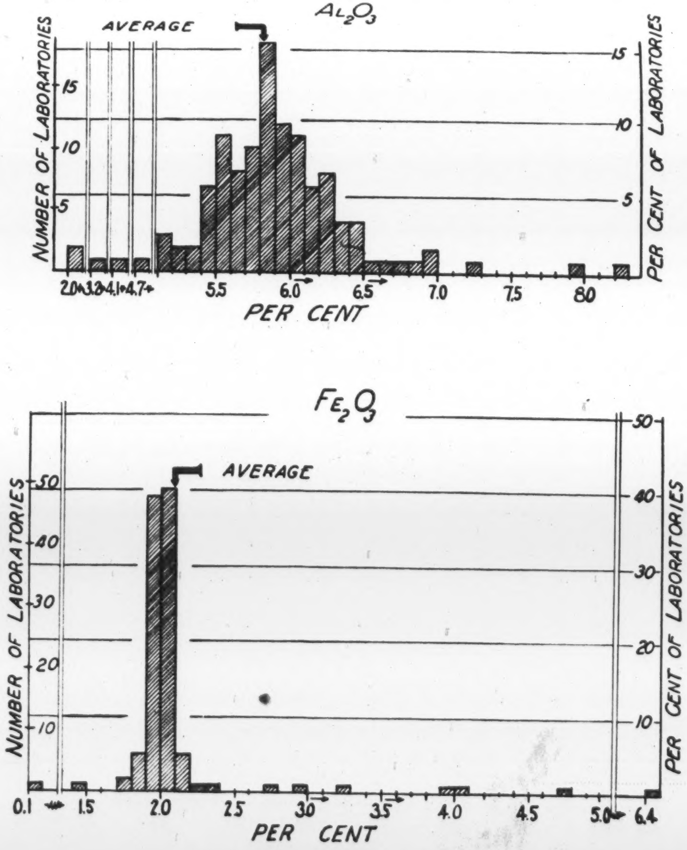
[3] 1937 Supplement to Book of A.S.T.M. Standards, p. 54.

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 738 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 468.



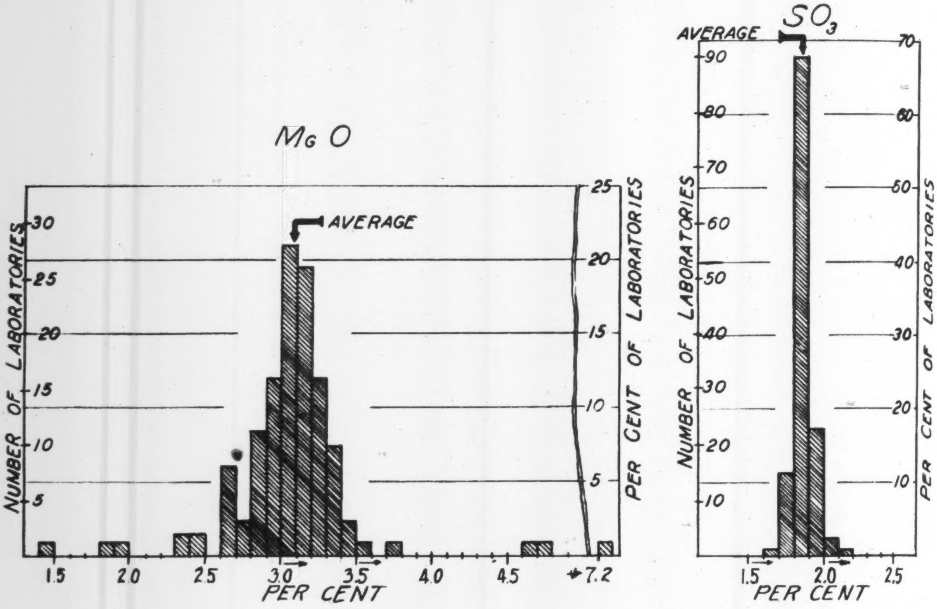
Class Interval 0.1 per cent.

FIG. 1.—Frequency Distribution of Results of Determinations of CaO and SiO_2.



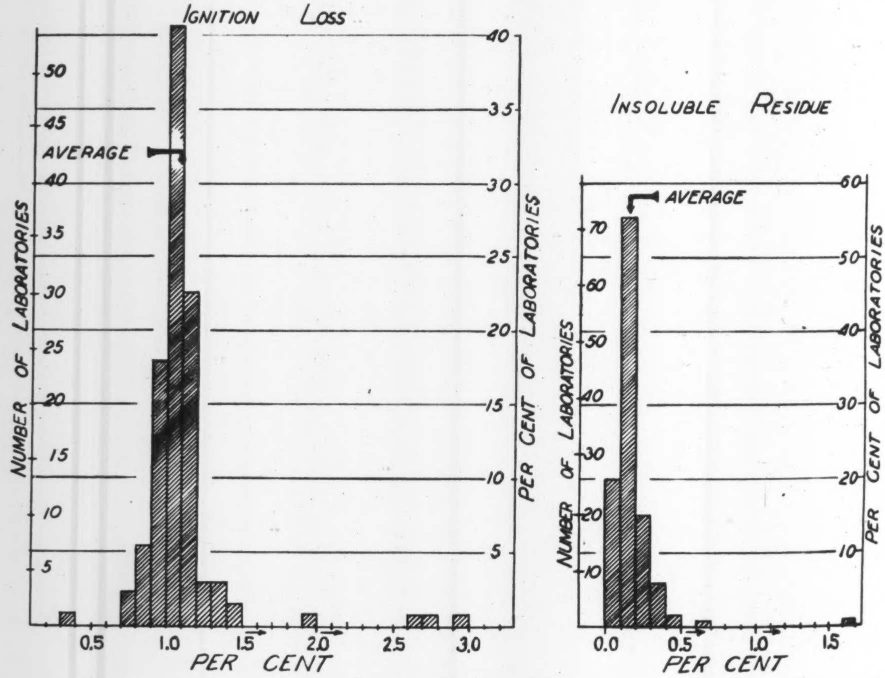
Class Interval 0.1 per cent.

FIG. 2.—Frequency Distribution of Results of Determinations of Al_2O_3 and Fe_2O_3.



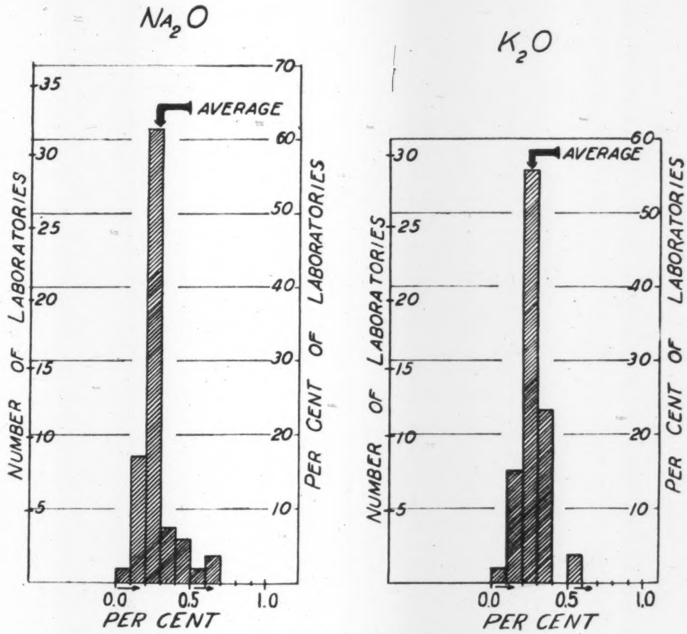
Class Interval 0.1 per cent.

FIG. 3.—Frequency Distribution of Results of Determinations of MgO and SO_3.



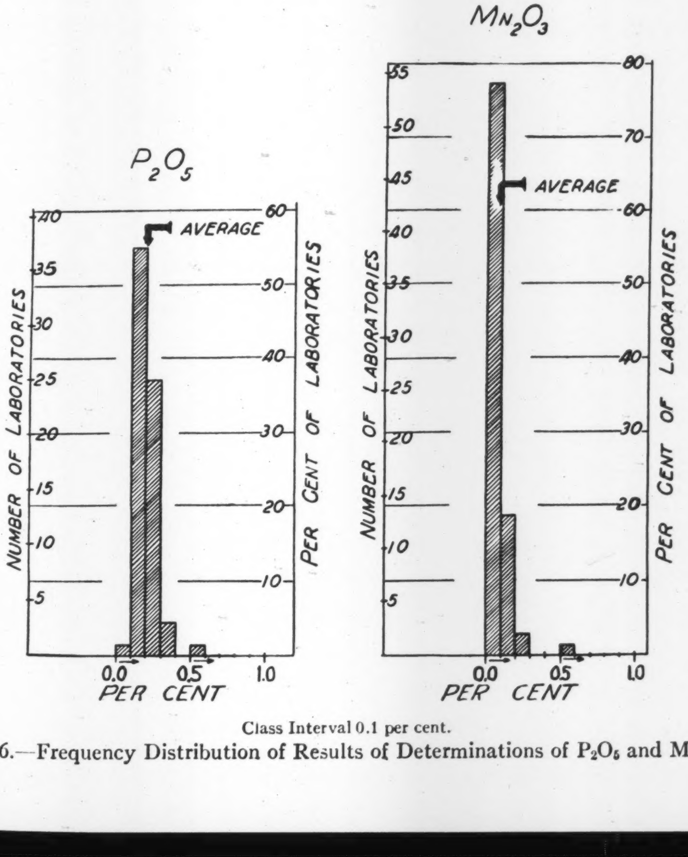
Class Interval 0.1 per cent.

FIG. 4.—Frequency Distribution of Results of Determinations of Ignition Loss and Insoluble Residue.



Class Interval 0.1 per cent.

FIG. 5 – Frequency Distribution of Results of Determinations of Na_2O and K_2O.



Class Interval 0.1 per cent.

FIG. 6.—Frequency Distribution of Results of Determinations of P_2O_5 and Mn_2O_3.

concluded therefrom that two decimal places are recommended as the appropriate manner to report the chemical determinations on cement.

Figures 1 to 6 show the frequency distribution of the results of determinations for the first twelve items in Table I.

Fineness:

The specific surface values as presented in Table II were determined with the Wagner turbidimeter. The specified procedure was that of the 1937 edition of the Tentative Method of Test for Fineness of Portland Cement by Means of the Turbidimeter (C 115 - 34 T).[5] The values were tabulated to the nearest 10 sq. cm. per g. Some laboratories reported variations from the specified method. The value for each laboratory was the average of results of three determinations.

TABLE II.—FINENESS.

Specific Surface, in sq. cm. per g., determined by the Wagner Turbidimeter.

	Specific Surface, sq. cm. per g.
Grand average of 102[a] laboratories	1810
Maximum	1990
Minimum	1690

After omitting 7 results (1990, 1990, 1990, 1940, 1940, 1710, 1690), there is obtained an average of 1800 sq. cm. per g. for those 95 laboratories which did not vary more than plus or minus 5 per cent from this revised average. The distribution of the values reported by the 102 laboratories with respect to this revised average of 1800 sq. cm. per g. is as follows:

DISTRIBUTION OF RESULTS

Range in Specific Surface, sq. cm. per g.	Deviation from Average, per cent[b]	Number of Laboratories
1700 and less	more than 5	1
1710 to 1740	more than 3, not over 5	4
1750 to 1770	more than 1, not over 3	22
1780 to 1820	not over 1	41
1830 to 1850	more than 1, not over 3	17
1860 to 1890	more than 3, not over 5	11
1900 and more	more than 5	6

[a] An additional laboratory reported a low value of 1600 sq. cm. per g. which was omitted from above summary since standard turbidimeter was not used.

[b] These values are given to the nearest per cent and specific surface values are considered to the nearest 10 sq. cm. per g.

Normal Consistency:

The results of the standard normal consistency determinations on neat-cement paste, made according to A.S.T.M. Method C 77 - 37,[3] are summarized in Table III.

TABLE III.—NORMAL CONSISTENCY.

	Normal Consistency
Grand average value (for 157 laboratories)	24.2 per cent
Maximum value	26.2 per cent
Minimum value	23.0 per cent

DISTRIBUTION OF RESULTS

Range in Percentage of Water for Normal Consistency	Number of Laboratories
less than 23.2	3
23.2 to 23.8	23
23.9 to 24.5	105
24.6 to 25.2	21
more than 25.2	5

Laboratories varying not over ± 0.2 per cent water from average	66
Laboratories varying not over ± 0.3 per cent water from average	105
Laboratories varying not over ± 0.5 per cent water from average	114

Time of Setting:

Setting times, determined by the standard Gillmore method as described

TABLE IV.—TIME OF SETTING (GILLMORE METHOD).

	Initial Set	Final Set
Grand average for 157 laboratories	3 hr. 40 min.	6 hr. 0 min.
Maximum	5 hr. 15 min.	9 hr. 30 min.
Minimum	2 hr. 25 min.	3 hr. 30 min.

DISTRIBUTION OF RESULTS

Initial Set

Departures from Average	Number of Laboratories
more than 1 hr., less than 1¼ hr. above avg	7
more than 45 min., less than 1 hr. above avg	8
more than 30 min., less than 45 min. above avg	8
more than 15 min., less than 30 min. above avg	29
15 min. above or below avg	55
more than 15 min., less than 30 min. below avg	24
more than 30 min., less than 45 min. below avg	12
more than 45 min., less than 1 hr. below avg	7
more than 1 hr., less than 1¼ hr. below avg	3
more than 1¼ hr., less than 1½ hr. below avg	1
more than 1½ hr., less than 1¾ hr. below avg	2
more than 1¾ hr., less than 2 hr. below avg	1

Final Set

Departures from Average	Number of Laboratories
more than 3 hr., less than 3½ hr. above avg	1
more than 2½ hr., less than 3 hr. above avg	0
more than 2 hr., less than 2½ hr. above avg	2
more than 1½ hr., less than 2 hr. above avg	4
more than 1 hr., less than 1½ hr. above avg	6
more than 30 min., less than 1 hr. above avg	24
30 min. above or below avg	77
more than 30 min., less than 1 hr. below avg	24
more than 1 hr., less than 1½ hr. below avg	12
more than 1½ hr., less than 2 hr. below avg	5
more than 2 hr., less than 2½ hr. below avg	2

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[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 777 (1935); also 1937 Book of A.S.T.M. Tentative Standards, p. 466.

in A.S.T.M. Method C 77 – 37,[3] are summarized in Table IV.

Soundness:

The usual 5-hr. steam test was made on neat cement pats by 158 laboratories. All of those laboratories reported satisfactory results. Steam chest temperatures below the allowable minimum were reported by 8 laboratories.

Tensile Strength:

Tensile strength tests, summarized in Table V, were made on standard 1:3 Ottawa sand mortar briquets prepared according to Method C 77 – 37,[3] the strengths being determined at four ages: 1, 3, 7, and 28 days. In the detailed tabulations the individual results were reported to the nearest 5 lb., which apparently was the custom with many of the laboratories. In the preparation of the tables of the larger report, the individual briquet strengths and the averages of each set of three specimens were tabulated to the nearest 5 lb., in the manner of reporting employed by most of the laboratories. However, in calculating the deviations from the grand averages, the averages for each laboratory were more closely computed.

TABLE V.—TENSILE STRENGTH OF 1:3 STANDARD MORTAR BRIQUETS.

	Tensile strength, psi.			
	1 day	3 days	7 days	28 days
Average	170	300	395	474
Maximum	225	360	480	555
Minimum	115	230	310	385
Average of deviations of laboratory results from grand average, per cent	8.7	5.9	5.6	4.5
Laboratories included in average	156	156	157	155

DISTRIBUTION OF LABORATORY RESULTS

Deviations from Grand Average, per cent	Number of Laboratories			
	1 day	3 days	7 days	28 days
Not over ± 5	60	84	81	101
More than ± 5, not over ± 10	44	45	52	40
More than ± 10, not over ± 15	26	21	21	10
More than ± 15	26	6	3	4

Compressive Strength:

Compressive strengths of 2-in. mortar cubes are summarized in Table VI. The specified test method was that described in the Tentative Method of Test for Compressive Strength of Portland-Cement Mortars (A.S.T.M. Designation: C 109 – 37 T).[6] When calculating the values for the larger report, the strengths and spreads were expressed to the nearest 5 lb. up to 1000 lb., to the nearest 10 lb. for greater strengths, although calculations of deviations from grand average were made more closely.

The reports of these cube tests con-

TABLE VI.—COMPRESSIVE STRENGTH OF 2-IN. MORTAR CUBES.

NOTE.—See Fig. 7.

	1 day	3 days	7 days	28 days
(*a*) Compressive strength, psi.: Grand average	718	1750	3200	5160
Maximum	1120	2420	4590	7950
Minimum	355	965	2180	2800
(*b*) Laboratories included in average	117	117	118	115
(*c*) Standard deviation for all laboratories, psi	123	241	420	710
(*d*) Coefficient of variation for all laboratories, per cent	17.1	13.8	13.1	13.8
(*e*) Coefficient of variation for 25 laboratories possessing temperature controlled work rooms, per cent	11.0	11.7	10.6	9.0
(*f*) Coefficient of variation for 10 laboratories (also included under item (*e*)) possessing temperature controlled work rooms belonging to one organization, and accustomed to comparative tests	11.2	7.7	6.5	5.2

DISTRIBUTION OF RESULTS OF ALL LABORATORIES

	Number of Laboratories			
	1 day	3 days	7 days	28 days
Deviation from Average Strength, per cent:				
Not over ± 5	30	41	42	38
More than ± 5, not over ± 10	31	37	33	44
More than ± 10, not over ± 15	19	11	20	13
More than ± 15	37	28	23	20

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[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 726 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 476.

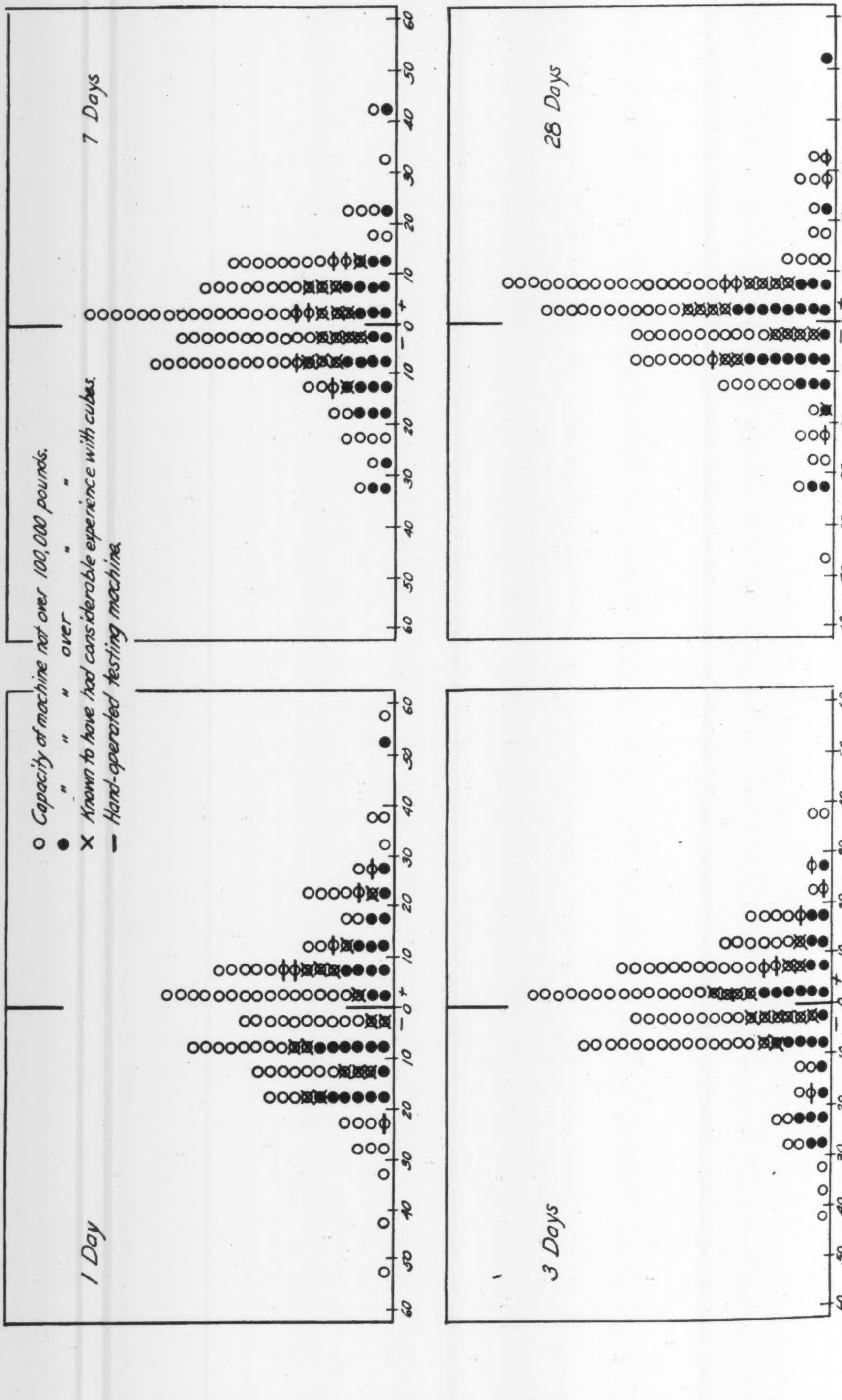

FIG. 7.—Frequency Distribution of Results of Compression Tests on 2-in. Cubes of Plastic Mortar.

tained numerous details not shown in this summary—details such as capacity of machine, rate of loading, bearing block designs, etc. These additional details will be studied as material for discussion in connection with any proposed revisions of Method C 109.

Figure 7 was prepared to show not only the frequency distribution of the test results, but also certain variables entering into the tests. Each dot, or circle, regardless of its markings, represents the result of one laboratory, there being in all approximately 115 laboratories represented for each test age.

The question of capacities of testing machines has often arisen in considering the tests of 2-in. cubes, particularly at early ages. The solid circles, or dots, represent machines of more than 100,000-lb. capacity, regardless of type of machine. A careful study of this feature of the graph is warranted. A few of the smaller capacity machines were hand-operated, and the results obtained on them are indicated by horizontal lines through the circles.

Since the 2-in. mortar cube, a tentative standard specimen, has not been so frequently made by some laboratories, as by others, it was thought advisable to learn what might be the relative positions of the results of those laboratories which were well experienced in the test. It was known that certain laboratories had either participated in some of the cooperative studies sponsored by the Working Committee on Plastic Mortar Tests, or had made many tests of 2-in. cubes. The results of these laboratories are identified by X-marks through the circles or dots. An examination of Fig. 7 will show that, in general, the results of these experienced laboratories are relatively near the average value.

Studies of reported temperatures did not throw much light on the question of how variations in temperature might have affected the strengths of the cubes. However, a comparison was made between the results of all laboratories and the results of 25 laboratories which possessed temperature controlled work rooms and, therefore, probably had very satisfactory temperatures throughout the test period. There then appeared a closer agreement in results within the smaller group than was evident for the entire number of laboratories. This is illustrated by items (*d*) and (*e*) in Table VI.

The two comparisons last mentioned lead to inquiry as to what might be the relative agreement within a group of 10 laboratories belonging to one organization, possessing temperature controlled work rooms, and accustomed to making comparative tests through a supervising central laboratory. The generally better agreement among these 10 laboratories, as shown by items (*d*), (*e*), and (*f*) of Table VI, appears as a favorable endorsement of temperature control and uniformity of procedure.

Autoclave Tests:

Autoclave tests were made according to the suggested method presented as Appendix I to the 1937 report[7] of Committee C-1, but with certain modifications. Since the preparation of the instructions for tests of sample No. 2, a revised proposed method, substantially as followed in these tests, has been published.[8] In the proposed test method is the requirement "Any test in which the percentage expansions of the individual specimens differ more than 0.05 shall be repeated." It is interesting to find that agreement reported between bars in these tests is well within those limits, the difference in percentage expansion between the

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[7] *Proceedings* Am. Soc. Testing Mats., Vol. 37, Part I, p. 290 (1937).

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 297 (1938).

FIG. 7.—Frequency Distribution of Results of Compression Tests on 2-in. Cubes of Plastic Mortar.

two bars in a set not exceeding 0.01 for 79 of the laboratories.

The modifications above referred to were: (1) the soaking period prior to autoclaving of bars was omitted, and (2) the bars were placed in boiling water immediately after opening of the autoclave, the water cooled to 21 C. (26.5 C. if preferred) in 15 min., then maintained at that temperature for an additional 15 min. when bars were to be removed and measured, as specified in the method later proposed.[8]

TABLE VII.—AUTOCLAVE EXPANSION TESTS OF NEAT-CEMENT BARS.

	Autoclave Expansion, per cent
Average for 82 laboratories	0.099[a]
Maximum	0.151[a]
Minimum	0.046[a]

DISTRIBUTION OF LABORATORY RESULTS

Deviation from Average Expansion, per cent	Number of Laboratories
Not over ± 0.010	27
More than ± 0.010, not over ± 0.020	31
More than ± 0.020, not over ± 0.030	15
More than ± 0.030, not over ± 0.040	4
More than ± 0.040	5

[a] Values reported by 2 additional laboratories were omitted from the calculations. Those values were 0.012 and 0.84 per cent.

The results of the autoclave tests are summarized in Table VII. Some few of the results were obtained using bars 4.6 to 6 in. in length, instead of the longer bar specified.

Temperature Data:

Some laboratories submitted temperature charts from recording instruments; some other laboratories reported temperature ranges. A digest of such data regarding laboratory room and storage equipment appears in the larger report and indicates whether and how storage apparatus temperatures were controlled. Temperature of mixing water and relative humidity of laboratory room were also included for parts of the work. Some further studies are being made of these data. It is encouraging to find that numerous laboratories have been equipped with temperature controlled work rooms.

GENERAL

The preparation and distribution of the sample, the larger detailed report, and this summary of the test results were conducted by the Cement Reference Laboratory.

REPORT OF SUBCOMMITTEE ON TESTS OF ADDITIONS TO CEMENT

In compliance with action taken at the June, 1938, meeting of Committee C-1, there was prepared and distributed to all of the members of Committee C-1 a summary of the results of tests made by the Cement Reference Laboratory to determine whether TDA was non-harmful in high-early-strength portland cement. This summary was an abstract of the lengthy report which had been prepared by the Reference Laboratory and transmitted to this subcommittee upon the completion of those tests.

The Dewey & Almy Chemical Co. completed arrangement with the A.S.T.M. to have TDA tested in normal portland cement. The money to defray cost of work was deposited with the Society and the laboratory work was started in February.

This second series of tests is being made on laboratory-ground cements. Six clinkers are being used. The clinkers were all received early in the year. The program of tests is not so extensive as for the first series and the tests have been modified to some extent from the procedure of the earlier investigation. The program includes chemical analyses of the clinkers, setting time and soundness tests, standard tensile strength tests at various ages up to at least six months, compressive strength tests for the same ages on 2-in. cubes of miniature concrete, freezing-and-thawing tests on bars of the same make-up as used for the cubes, turbidimeter fineness tests, autoclave tests, and some miscellaneous determinations.

This second series of tests is being performed by Mr. H. J. Kurtz who also conducted the tests made by the Cement Reference Laboratory on TDA and high-early-strength cements.

Respectfully submitted on behalf of the subcommittee,

H. J. Gilkey,
Chairman.

REPORT OF COMMITTEE C-5
ON
FIRE TESTS OF MATERIALS AND CONSTRUCTION

Committee C-5 on Fire Tests of Materials and Construction has held no meeting since the annual meeting of the Society in June, 1937, nor have any of its subcommittees held any formal meetings. The committee has carried on its work by correspondence, as the investigations being made preparatory to the formulation of specifications have not yet reached the stage where definite provisions can be drafted and subjected to discussion at a meeting.

Committee C-5 has promulgated only one standard, namely, the Standard Specifications for Fire Tests of Building Construction and Materials (C 19 – 33). With the advent of the 1939 annual meeting of the Society, this standard will have stood six years without revision. Because of the economic condition of recent years the standard has not had extensive application during that period. Such use as has been made since its adoption in 1933 has not developed deficiencies or difficulties to require revision, and it is still considered to be in accord with present good practice. Its continuance in its present status is recommended.

There is one existing tentative standard under the jurisdiction of Committee C-5, namely, the Tentative Specifications for Fire-Retardant Properties of Wood for Scaffolding and Shoring (C 132 – 37 T). Experience with these specifications during the past year has been limited, and no criticisms nor requests for revision have been received. The committee is not prepared to suggest their adoption as standard as it feels that further experience is desirable. It is recommended that the specifications be continued as tentative for another year.

This report has been submitted to letter ballot of the committee which consists of 30 members; 27 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

R. P. Miller,
Chairman.

H. M. Robinson,
Secretary.

REPORT OF COMMITTEE C-7

ON

LIME

Two regular meetings of Committee C-7 on Lime were held during the year: the first on June 10, 1938, at Chalfonte-Haddon Hall, Atlantic City, N. J., and the second on March 9, 1939, at the Deshler-Wallick Hotel, Columbus, Ohio.

Committee C-7 sponsored an extensive Symposium on Lime at the A.S.T.M. Regional Meeting in Columbus, Ohio, on March 8, 1939. The symposium, comprising eleven papers, covered various phases of tests and properties of lime and lime products, and presented information and data from the standpoint of both research and experience. Approximately two hundred persons attended the symposium. The list of papers[1] presented is as follows:

"Variations in Properties of Dolomitic Lime Putties with Method of Hydration," by John E. Conley,

"The Hydration of Magnesian Lime and the Autoclave Test," by F. C. Welch,

"Manufacturing Lime for the Glass Industry," by A. H. Nieman,

"Factors Affecting Milks of Lime Employed in Industry," by D. E. Washburn,

"Quality of Lime Desired for Water Treatment," by Charles P. Hoover,

"Prevention of After-Precipitation in Lime-Treated Industrial and Municipal Waters by Threshold Treatment," by Owen Rice, Everett P. Partridge, and R. E. Hall,

"Soil Acidity and Liming, and Some Factors that should Determine the Standards for Lime for the Soil," by E. O. Fippin,

"Criteria for the Evaluation of Agricultural Ground Limestone," by R. M. Salter and C. J. Schollenberger,

"Preliminary Investigation of the Determination of Fluorine in Lime," by C. J. Koehler

"Fundamental Mechanics of Calcination and Hydration of Lime and Methods of Control," by Victor J. Azbe, and

"Lime Characteristics and Their Effect on Construction," by Walter C. Voss.

During the year the following were elected to membership on Committee C-7:

Kermit Herndon, Ohio State University,

F. S. Pritchett, Delaware Testing Laboratories,

H. C. Plummer, Structural Clay Products Institute,

W. C. Voss, Massachusetts Institute of Technology, and

H. H. Waples, Procurement Division, U. S. Treasury Department.

Since the election of these new members more than balances the committee with respect to producers and nonproducers, the election of S. G. Price, Gibsonburg Lime Products Co., now becomes effective. Mr. Price qualified for membership on April 28, 1937, and was approved by the committee at a meeting held on June 10, 1938, to become effective when the balance of the committee would permit. The membership of the committee now totals 50, classified as 25 producers, 7 consumers, and 18 general interest members.

The only new tentative specifications approved by Committee C-7 during the year were the Tentative Specifications for Hydraulic Hydrated Lime for

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[1] Symposium on Lime, Columbus Regional Meeting, Am. Soc. Testing Mats. (1939), available as a separate publication.

Structural Purposes (C 141 – 38 T). These specifications originated in Subcommittee X on Hydraulic Lime (W. E. Carson, chairman) which was organized as a result of action taken at the meeting of Committee C-7 held in Chicago on June 25, 1931. At the meeting of Committee C-7 in Washington, D. C., on March 7, 1934, Mr. Carson presented a report from Subcommittee X stating that a special committee, comprising L. S. Wells and J. A. McCormick, had been appointed and instructed to prepare a draft of specifications for hydraulic lime. A copy of the draft entitled "Eminently Hydraulic Lime" was presented, discussed, and made an appendix to the minutes of the meeting. From 1934 to 1938 these proposed specifications were reviewed at various meetings of Committee C-7 and revised in accordance with the comments and suggestions received. On June 30, 1938, at the meeting of Committee C-7 in Atlantic City, N. J., the specifications, as drafted, were approved by the committee and subsequently presented to the Society through Committee E-10 on Standards. There were no new methods of testing included in these specifications. The specifications were accepted[2] for publication as tentative on August 25, 1938, and appear in the 1938 *Proceedings*.[3]

Subcommittee III on Lime for the Chemical Industries (D. E. Washburn, chairman) is continuing its study of the Proposed Specifications for Quicklime for Causticizing Leached Liquors in the Soda-Pulp Process for the Manufacture of Paper, for Quicklime for Use in the Manufacture of Paper Pulp Where the Precipitated Carbonate is Employed as a Pigment or Filler, and of the Proposed Method for Determination of Available Lime in High-Calcium Quicklime and Hydrated Lime by the Rapid Sugar Test, which were published as information last year.[4]

Subcommittee VIII on Nomenclature and Definitions (W. E. Carson, chairman), in attempting to prepare a comprehensive definition for the term "lime," has compiled from numerous sources an extensive list of definitions for this term which has been distributed to the membership of Committee C-7 for study and comment.

Subcommittee IX on Research Problems (J. R. Withrow, chairman) was instrumental in arranging for the Symposium on Lime, referred to above. The papers of this symposium indicate that there is a considerable interest in research on various lime problems.

I. REVISION OF STANDARDS

For the sake of simplicity and to incorporate certain editorial changes, the committee recommends that the Standard Specifications for Quicklime for Use in Water Treatment (C 53 – 27),[5] and for Hydrated Lime for Use in Water Treatment (C 54 – 27)[5] be combined into a single specification entitled "Standard Specifications for Quicklime and Hydrated Lime for Water Treatment."[6] The committee asks for the necessary nine-tenths vote at the annual meeting in order that this recommendation may be referred to letter ballot of the Society for immediate adoption.

II. ADOPTION OF TENTATIVE STANDARD AS STANDARD

The Tentative Specifications for Sand for Use in Plaster (C 35 – 36 T),[7] under the joint jurisdiction of Committee C-11 on Gypsum and Committee C-7, are being revised to limit the amount of saline, alkaline, or organic substances. As previously written, Section 3 on Deleterious Substances permitted 5 per cent of material finer than 200 mesh. This could be interpreted to allow as much as 5 per cent of saline, alkaline, or organic material, whereas it was intended to refer only to fine sand. The words "deleterious substances" have been deleted, and Section 3 has been made Section 2 (*b*) under "Grading." Committee C-7 has approved these revisions, which are given in detail in the report of Committee C-11 being presented at this annual meeting.[8] Committee C-7 concurs with Committee C-11 in recommending that Specifications C 35 as revised be approved for reference to letter ballot of the Society for adoption as standard.

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[2] In submitting these tentative specifications to Committee E-10 on Standards, Committee C-7 reported results of the letter ballot vote as follows: Of a total membership of 43, 38 members returned their ballots, of whom 27 voted affirmatively, 4 negatively, and 7 members marked their ballots "not voting."

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 757 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 500.

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 306 to 309 (1938).

[5] 1936 Book of A.S.T.M. Standards, Part II, pp. 38, 40.

[6] These specifications were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 771 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 505.

III. Adoption as Standard of Tentative Revision of Standard

At the June, 1938, meeting of the committee a tentative revision was approved of the Standard Definitions of Terms Relating to Lime (C 51 - 28).[9] This modification comprised the substitution of the word "activity" for the word "affinity" in the definition of the term "hydrated lime." It was the opinion of the committee that the word "affinity" was indefinite and unscientific. Subsequent to the 1938 annual meeting Committee C-7 presented this revision to the Society through Committee E-10 on Standards. The revision was accepted[10] for publication as tentative on August 25, 1938, and appears in the 1938 *Proceedings*.[11]

At the March, 1939, meeting of the committee further consideration was given to this proposed change. It was pointed out that by usage over a considerable period of time the trade had become familiar with the word "affinity" and understood its meaning. To further clarify the definition for hydrated lime, it was suggested that the phrase "for water" be inserted directly following the word "affinity" to prevent possible misinterpretation that combination might be with chemicals other than water. The committee accordingly recommends that the tentative revision published last year be further revised, as given below, and asks for the necessary nine-tenths vote at the annual meeting in order that this recommendation may be referred to letter ballot of the Society for immediate adoption:

Hydrated Lime.—Change this definition to read as follows by the addition of the italicized words and the omission of the word in brackets:

> Hydrated Lime.—A dry powder obtained by treating quicklime with water enough to satisfy its chemical [activity] *affinity for water* under the conditions of its hydration.

IV. Standards and Tentative Standards Continued Without Revision

The following standards and tentative standards which have stood for a number of years without revision have been reviewed, and changes of an editorial nature have been made:

Standard Specifications for:

Quicklime and Hydrated Lime for Cooking of Rags in the Manufacture of Paper (C 45 - 25),

Quicklime for Use in the Manufacture of Sulfite Pulp (C 46 - 27),

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[8] See report of Committee C-11 on Gypsum, p. 366.

[9] 1936 Book of A.S.T.M. Standards, Part II, p. 72.

[10] In submitting this revision to Committee E-10 on Standards, Committee C-7 reported results of the letter ballot vote as follows: Of a total membership of 43, 38 members returned their ballots, of whom 31 voted affirmatively, 1 negatively, and 6 members marked their ballots "not voting."

[11] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1325 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1691.

- Hydrated Lime for the Manufacture of Varnish (C 47 – 27),
- Quicklime and Hydrated Lime for Use in the Textile Industry (C 48 – 24),

Standard Methods of:

- Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (C 25 – 29),
- Sampling, Inspection, Packing, and Marking of Quicklime and Lime Products (C 50 – 27),

Tentative Specifications for:

- Quicklime for Structural Purposes (C 5 – 34 T),[12] and
- Hydrated Lime for Structural Purposes (C 6 – 34 T).[12]

The latter two tentative specifications are in effect a tentative revision of the existing Standard Specifications C 5 – 26 and C 6 – 31.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 50 members; 27 have returned their ballots, with the results shown in Table I.

This report has been submitted to letter ballot of the committee which consists of 50 members, 36 members returned their ballots, of whom 35 have voted affirmatively and 0 negatively.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF STANDARDS			
Spec. for Quicklime for Use in Water Treatment (C 53 – 27), and for Hydrated Lime for Use in Water Treatment (C 54 – 27), combined into a single specification, immediate adoption	21	1	5
II. ADOPTION OF TENTATIVE STANDARD AS STANDARD			
Spec. for Sand for Use in Plaster (C 35 – 36 T), as revised	26	0	1
III. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD			
Definitions of Terms Relating to Lime (C 51 – 28), definition of hydrated lime	26	0	1

Respectfully submitted on behalf of the committee,

J. R. WITHROW,
Chairman.

J. W. STOCKETT, JR.
Secretary.

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[12] See Editorial Note below.

EDITORIAL NOTE

Subsequent to the annual meeting Committee C-7 presented to the Society through Committee E-10 on Standards a recommendation for withdrawal of the Tentative Specifications for Quicklime for Structural Purposes (C 5 – 34 T) and for Hydrated Lime for Structural Purposes (C 6 – 34 T). This recommendation was accepted by Committee E-10 on August 24, 1939. The existing Standard Specifications for Quicklime for Structural Purposes (C 5 – 26) and for Hydrated Lime for Structural Purposes (C 6 – 31) are retained as standard and appear in the 1939 Book of A.S.T.M. Standards, Part II.

REPORT OF COMMITTEE C-8
ON
REFRACTORIES

Committee C-8 on Refractories held two meetings during the year: in Bedford Springs, Pa., on September 1, 1938, and in Columbus, Ohio, on March 7, 1939. The former meeting was held in conjunction with the summer meeting of the Refractories Division of the American Ceramic Society, and the latter meeting was in conjunction with the spring group meetings of the Society.

The committee has been quite active during the year and has brought forth several distinct improvements in existing procedures, which are being recommended for adoption.

A new Section on Retest Data (L. J. Trostel, chairman) has been formed for the purpose of obtaining the information necessary for establishing the requirements of retesting clauses in the several C-8 specifications. This section has made progress in obtaining fundamental information along these lines.

A Joint Committee (R. H. Heilman, chairman) has been formed to serve with Committee C-16 on Thermal Insulating Materials on matters pertaining to high-temperature insulation to prevent any overlapping of activities of the two committees.

I. New Tentative Standard

The present Standard Method of Test for Refractory Materials Under Load at High Temperatures (C 16 – 36) has been in need of revision for quite some time. The committee has now completed a new procedure for this test which incorporates several worth-while changes, together with new furnace designs. Portions of the old procedure, which pertain to the testing of silica brick, have been omitted because it has been known for some time that the test is of little use in evaluating present-day silica brick. The present furnace design is retained and, in addition, there are included two new types of furnaces embodying a direct load for the specimen in place of the present use of levers. One of these furnaces is electrically heated, and the other is an improved design for use with either gas or oil as fuel. It is accordingly recommended that the new Tentative Method of Test for Fireclay and Alumina-Diaspore Refractories Under Load at High Temperatures[1] be accepted for publication as tentative to replace the present Standard Method C 16 – 36.[2]

II. Revisions of Tentative Standards

During the year the committee has evolved a new procedure for measuring refractory brick and shapes for size, and for determining bulk density. This represents an improvement and a revision of the present Tentative Methods of Test for Size, Warpage, and Bulk Specific Gravity of Refractory Brick (C 134 – 38 T).[3] The committee accordingly recommends that the revised procedure entitled "Tentative Methods of Test for Size and Bulk Density of Refractory Brick"[1] be accepted for publication to replace the present Tentative Methods C 134 - 38 T.

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[1] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

[2] 1936 Book of A.S.T.M. Standards, Part II, p. 224.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 791 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 601.

Studies of the Tentative Methods of Testing High-Temperature Heat Insulation (Compression, Flexure, Shrinkage) (C 93 - 34 T)[4] have resulted in two recommendations. The order of accuracy in measuring samples for the shrinkage test is being changed from "0.01 in." to read "0.02 in.," and improved procedures are presented for determining the compressive and flexural strengths. It is recommended that the revised methods entitled "Tentative Methods of Testing Insulating Fire Brick (Compression, Flexural Strength, and Permanent Linear Change after Heating)"[1] be accepted for publication as tentative.

III. TENTATIVE REVISIONS OF STANDARDS

Recent studies have brought forth an additional factor of control in the preheating operation of the panel spalling test. Accordingly, the committee is presenting for publication as tentative the following revision of the Standard Method of Panel Test for Resistance to Thermal and Structural Spalling of High Heat Duty Fireclay Brick (C 107 - 36),[5] and of Super-Duty Fireclay Brick (C 122 - 37):[6]

Section 4.—Add a new paragraph as Paragraph (*d*) and a Note to read as follows:

> (*d*) The furnace gas pressure during the 24-hr. preheating period shall be within the limits of 0.3 to 0.6 in. of water for gas-fired furnaces.
>
> NOTE.—In furnaces used for the purpose of obtaining control or experimental data, and when the method is followed in all details except that oil is used as a fuel, it is recommended that the furnace gas pressure be maintained between 0.1 and 0.2 in. of water.

IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative standards be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of Test for Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (C 133 - 37 T),[7]

Tentative Methods of Chemical Analysis of Refractory Materials (C 18 - 37 T),[7]

Tentative Symbols for Heat Transmission (C 108 - 34 T),[8] and

Tentative Definitions of 50 per cent, 60 per cent, and 70 per cent Alumina-Diaspore Refractories appearing in the Tentative Definitions of Terms Relating to Refractories (C 71 - 37 T)[7] to be added to the Standard Definitions for Fireclay Refractories (C 27 - 37).

V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

The committee recommends that the revisions published as tentative[9] last year in the following three specifications be approved for reference to letter ballot of the Society for adoption as standard with the section on permissible variations modified as given below:

Standard Specifications for:

Fireclay Brick for Malleable Furnaces with Removable Bungs and for Annealing Ovens (C 63 - 36),

Fireclay Brick for Stationary Boiler Service (C 64 - 36), and

Refractories for the Construction of Incinerators (C 106 - 36).

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part I, p. 791 (1934); also 1938 Book of A.S.T.M. Tentative Standards, p. 596.

[5] 1936 Book of A.S.T.M. Standards, Part II, p. 220.

[6] 1937 Supplement to Book of A.S.T.M. Standards, p. 83.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I pp. 785, 760, 790 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 591, 566, 606.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part I, p. 807 (1934); also 1938 Book of A.S.T.M. Tentative Standards, p. 608.

[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1321 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1687.

Section 2.—Change from its present form to read as follows:

> 2. When tested according to the Tentative Methods of Test for Size and Bulk Density of Refractory Brick (A.S.T.M. Designation: C 134),[4] the standard 9-in. fire-clay brick shall not show a size variation of more than plus or minus 2 per cent. Tile or shapes shall not show a size variation of more than plus or minus 2 per cent on dimensions of 4 in. or over, and plus or minus 3 per cent on dimensions smaller than 4 in.

VI. WITHDRAWAL OF STANDARDS

It is recommended that the following two standards be withdrawn:

Standard Specifications for Clay Fire Brick for Marine Boiler Service (C 65 – 28);[10] this standard has served its period of usefulness and circumstances are such that it is not in order for the committee to attempt to revise it.

Standard Method of Test for Refractory Materials Under Load at High Temperatures (C 16 – 36),[10] to be replaced by new Tentative Method of Test for Fireclay and Alumina-Diaspore Refractories Under Load at High Temperatures.[1]

The recommendations appearing in this report have been submitted to letter ballot of the committee, which consists of 33 members, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Test for Fireclay and Alumina-Diaspore Refractories Under Load at High Temperatures (C 16 – 39 T)	27	1	2
II. REVISIONS OF TENTATIVE STANDARDS			
Test for Size, Warpage, and Bulk Specific Gravity of Refractory Brick (C 134 – 38 T)	29	1	0
Testing High-Temperature Heat Insulation (Compression, Flexure, Shrinkage) (C 93 – 34 T)	25	0	4
III. TENTATIVE REVISIONS OF STANDARDS			
Panel Test for Resistance to Thermal and Structural Spalling of High Heat Duty Fireclay Brick (C 107 – 36)	28	0	2
Panel Test for Resistance to Thermal and Structural Spalling of Super Duty Fireclay Brick (C 122 – 37)	28	0	2
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test for Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (C 133 – 37 T)	29	0	1
Chemical Analysis of Refractory Materials (C 18 – 37 T)	30	0	0
Symbols for Heat Transmission (C 108 – 34 T)	28	0	0
Definitions of Terms Relating to Refractories (C 71 – 37 T), three definitions	27	0	3
V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Spec. for Fireclay Brick for Malleable Furnaces with Removable Bungs and for Annealing Ovens (C 63 – 36)	27	1	2
Spec. for Fireclay Brick for Stationary Boiler Service (C 64 – 36)	27	1	2
Spec. for Refractories for the Construction of Incinerators (C 106 – 36)	27	1	2
VI. WITHDRAWAL OF STANDARDS			
Spec. for Fireclay Brick for Marine Boiler Service (C 65 – 28)	30	0	0
Test for Refractory Materials Under Load at High Temperatures (C 16 – 36)	27	0	3

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Industrial Survey (L. C. Hewitt, chairman) has continued in its productive work in the preparation of industrial surveys. Two new surveys were completed during the year, one for Conditions Surrounding Refractory

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[10] 1936 Book of A.S.T.M. Standards, Part II, pp. 200, 224.

Service in Lime Burning,[14] and the other on Conditions Surrounding Refractory Service in Continuous Plate Glass and Window Glass Furnaces.[15] These have been referred to letter ballot of the committee, which consists of 33 members, for approval for inclusion in the next edition of the Manual of A.S.T.M. Standards on Refractory Materials. On the former survey, 28 members returned their ballots, of whom 24 voted affirmatively, 0 negatively, and 4 members marked their ballots "not voting"; on the latter, 30 members returned their ballots, of whom 28 voted affirmatively, 1 negatively, and 1 member marked his ballot "not voting." The subcommittee is considering a new list of subjects for the selection of its next study.

Subcommittee II on Research (R. S. Bradley, chairman) reports progress on the investigation of the design of back-up insulation for the panels in the panel spalling test. In conjunction with the Section on Spalling, this subcommittee is endeavoring to collect confirming data from several laboratories to show any variation of results that might be expected from the suggested revision of the procedure.

Work has been done on the thermal analysis of clays as a means of estimating rapidly the clay minerals present in raw clay.

Because of interest in long-time load tests, there has been collected an appreciable amount of data from tests using a 24-hr. holding period in place of the usual 1½ hr. The information shows that even after the 24-hr. period, the brick continue to subside. It appears that periods of 8 to 10 hr. would be as useful as 24 hr. to show the relative properties of types of brick.

Subcommittee III on Tests (F. A. Harvey, chairman) is comprised of the chairmen of the seven sections mentioned below. The subcommittee has developed a new method for measuring size and bulk density of fireclay brick, which is an improvement over the present method (C 134 – 38 T), giving more definite and detailed directions and the description of a procedure for making stack measurements. It includes a method for determining bulk density but does not contain a method for measuring warpage; this is to be the subject of a separate procedure.

Section A on Load (C. M. Dodd, chairman) has carried out a considerable amount of work in the study of the load test, resulting in a revised procedure which omits the test for silica brick and stipulates certain conditions which have been in general use but which were not incorporated in the present procedure (C 16 – 36). For example, 25 psi. is the established load, the furnace is required to be operated with an oxidizing atmosphere above 800 C., and no specification is placed on the exact design of equipment used. There are included two new designs of furnaces which employ a direct load in place of the use of a lever; one furnace is heated electrically, and the second makes use of gas or oil.

Section B on Spalling (R. E. Birch, chairman) has studied details of the panel spalling procedure (C 107 – 36 and C 122 – 37) for the purpose of standardizing to a further degree the factors contributing to reproducibility of test results. Recommendations are being made for standardizing the furnace gas pressure during the 24-hr. preheat period. Studies have shown that this is an important factor in heat penetration and consequent spalling loss. The back-up insulation work has been continued with promising results, and studies of the factors involved during the heating-up period just prior to spalling are being made.

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[14] See p. 345.
[15] See p. 349.

Section C on Temperature (R. B. Sosman, chairman) has collected useful information on the operation of the several types of P.C.E. furnaces now used. This has been made available to the members of the committee, but as yet no recommendation concerning exact furnace design can be offered.

Section D on Slagging (C. E. Bales, chairman) has prepared a review of the literature on slag tests that have been developed and used in recent years. Comparatively little is being done on the slag test except the continuation of the work at the University of Illinois, which has to do with minor changes in their equipment and the correlation of the test data with actual service trials.

Section E on Analysis (L. J. Trostel, chairman) is recommending the adoption as standard of the Tentative Methods of Chemical Analysis of Refractory Materials (C 18 – 37 T) in view of the fact that no further changes or refinements are imminent.

Section F on Tests on Refractory Insulation (W. C. Rueckel, chairman) has developed a revision of the methods for determining the compressive and flexural strengths of insulating fire brick which is recommended for publication as tentative, replacing the present Methods C 93 – 34 T. The section has made considerable progress in one phase of its work by collecting useful information on the subject of testing insulating block. Committee C-8 has reaffirmed its belief that its activities should include insulating materials which are used in the temperature range from 1000 F. upward.

Section G on Porosity and Permanent Volume Change (C. E. Fulton, chairman) is obtaining basic information on the factors related to the determination of porosity and volume of refractory materials. A progress report has given information on the size of sample, order of accuracy necessary in weighing, methods of filling the pores with water or other liquids, and the differences in porosity resulting from the position in the brick from which the test sample was taken. This work will result in a revision of the present Standard Method of Test for Porosity and Permanent Volume Changes in Refractory Materials (C 20 – 33).

Subcommittee IV on Heat Transfer (R. H. Heilman, chairman) is working in cooperation with the National Bureau of Standards in an endeavor to develop a more refined method for determining thermal conductivity so as to obtain a greater degree of accuracy. The work to date covers principally the calorimeter and a more satisfactory means of obtaining good contact between the sample and the test equipment.

Several members of the committee are carrying out comparative tests on block insulation to determine the order of accuracy which might be expected when testing this material by present-day procedures and equipment.

Subcommittee V on Precision and Tolerance (R. A. Heindl, chairman) is developing a procedure to be used in the selection of clay samples in connection with the ground fireclay specifications; this is needed to complete the specifications for the trade.

Section A on Retest Data (L. J. Trostel, chairman) is conducting a statistical study to learn the order of variation which may be expected in the data obtained from the different tests. In this way it is expected that the committee will learn the limits of accuracy which may be expected from each test, and so provide the information necessary to prepare retest clauses for use in the several A.S.T.M. specifications covering the selection of refractory materials. This information is of a basic nature, applying not only to retesting but also in the general use of these tests.

Subcommittee VI on Nomenclature (M. E. Holmes, chairman) is at present making a critical study of many of the present definitions, looking toward revising them so as to make them more specific. R. B. Sosman has been unable to devote time to this committee work because of other activities, and M. E. Holmes has taken over the chairmanship.

Subcommittee VII on Specifications (G. A. Bole, chairman) plans to cooperate with Committee C-7 on Lime in revising the Standard Specifications for Lime for the Manufacture of Silica Brick (C 49 – 24) in view of more recent practice in the silica brick industry.

The subcommittee is recommending the withdrawal of the specifications for fireclay brick for marine boiler service (C 65 – 28) because they have outlived their usefulness and circumstances are such that it is not in order to revise them in line with present maritime practice.

A recommendation is being made to incorporate new and more rigid size tolerances in the specifications for fireclay brick (C 63 and C 64) and for refractories (C 106) in view of the new method for measuring size.

Subcommittee VIII, Editorial (L. J. Trostel, chairman) has cooperated with Society Headquarters in preparing the standards of the committee for printing in the new double column format, which has recently been adopted. The Refractories Manual will be revised in the fall of 1940, making it a triennial edition.

This report has been submitted to letter ballot of the committee which consists of 33 members; 27 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. D. SULLIVAN,
Chairman.
E. H. VAN SCHOICK,
Vice-Chairman.

S. M. PHELPS,
Secretary.

EDITORIAL NOTE

Subsequent to the annual meeting Committee C-8 presented to the Society through Committee E-10 on Standards the following recommendations:

Proposed Tentative Methods of Test for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Products (C 20 – 39 T), to replace the Standard Method of Test for Porosity and Permanent Volume Changes in Refractory Materials (C 20 – 33),

Proposed revisions of the Tentative Definitions of Terms Relating to Refractories, (C 71 – 37 T), and

Proposed tentative revision of Standard Symbols for Heat Transmission (C 108 – 39).

These recommendations were accepted by Committee E-10 on December 4, 1939, and the new tentative standards and tentative revision appear in the 1939 Book of A.S.T.M. Standards, Part II.

APPENDIX I

INDUSTRIAL SURVEY OF CONDITIONS SURROUNDING REFRACTORY SERVICE IN LIME BURNING

Burnt lime, as it comes from the kilns, is nearly pure calcium oxide, or a mixture of calcium and a lesser amount of magnesium oxide. It may be of primary or secondary origin depending upon whether it is the product of calcination of naturally occurring calcium or magnesium carbonate rock or whether it is recovered from some industrial process. Primary lime is made from nearly pure calcite, dolomite, a mixture of calcite and dolomite, or a massive variety of marine fossils. Oyster shells are also sometimes used. Secondary lime may be made from various lime-wastes, such as the lime-sludge from paper mills, sugar purification, or caustic soda manufacture.

Most of the lime in this country is made in Ohio, Pennsylvania, Missouri, and West Virginia. Slightly over one-half of the production is chemical lime, about one quarter is building lime, and the remainder is divided between agricultural lime and refractory lime (dead-burned dolomite).[1]

Kilns

Two kinds of continuous kilns are now generally used: the vertical and rotary. Vertical kilns are of the separate feed type in which the limestone and fuel are not brought into contact, or the mixed feed types in which stone and fuel are charged in alternate layers. Most vertical kilns of the separate feed type are fired with coal, but some of the more modern kilns use gas, either natural or producer, and oil. A few plants still use wood. The mixed feed vertical kilns use coke or anthracite coal. Rotary kilns use coal, oil, or gas. A typical separate feed vertical kiln is shown in Fig. 1 and a rotary kiln in Fig. 2.

The process of lime burning in continuous kilns is comparatively simple. Stone of proper size is fed into the cold end where drying out takes place; it then passes to the preheating or calcining section, then to the burning zone, and finally to the cooling end. The rate of flow through the kiln depends upon the capacity and time required to burn the charge thoroughly. The capacity of modern vertical kilns ranges from 20 to 100 tons per day. Rotaries range from 40 to 150 tons per day on high-calcium lime and slightly more for magnesian limes.

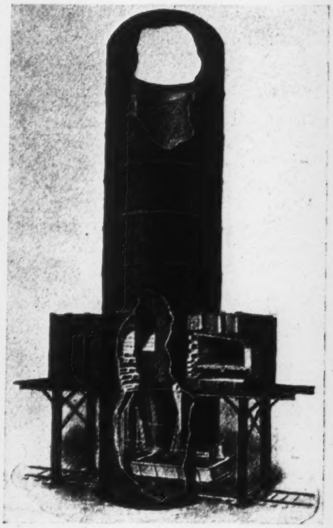

FIG. 1.—Vertical Kiln.

Burning temperatures are designed to completely drive off all the carbon dioxide. The temperature necessary for high-calcium stone is somewhat higher than that required for magnesian limestones. A loss in weight occurs in burning, due to liberation of the carbon dioxide. This would amount to about 44 per cent for pure calcite and about 52 per cent for pure magnesium carbonate.

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[1] Reference has been omitted in this survey to the refractory practice in the manufacture of dead-burned dolomite, since it is more comparable with the manufacture of portland-cement clinker.

REFRACTORY REQUIREMENTS

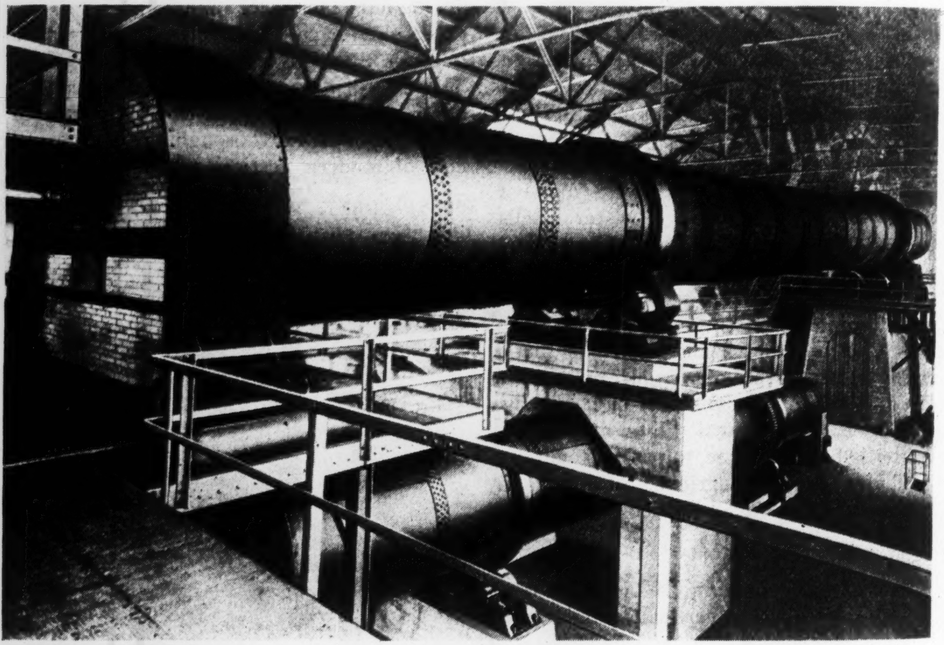
While the design and operation of vertical and rotary kilns are greatly different in some respects, the refractory requirements of the lining material are frequently similar. Based on the flow of the material and the reactions taking place, kilns may be divided into four zones, common to each type with some overlapping of adjacent zones. In addition, the refractory requirements of the coolers which are part of the auxiliary equipment of rotary kilns must be considered. Schematic drawings indicating these zones are shown in Fig. 3.

Zone No. 1, the raw-feed end of the kiln requires a brick that is very hard in order to resist the abrasion of the incoming charge. The brick must also be dense to prevent absorption of moisture, frequently present in wet or frozen rock charged into vertical kilns, and the wet slurries sometimes charged into rotaries.

Zone No. 2, in which the calcination of the stone commences, is not typified by conditions of unusual severity, since the temperatures are too low to cause reaction between the burden and the lining. Furthermore, this zone, being considerably beyond the feed end, is not subject to the sudden changes in temperature which cause spalling.

Zone No. 3, or the burning zone in which the most intense temperatures prevail, calls for a refractory best able to resist reaction with the lime and certain impurities. Some of these impurities, such as clay, may be associated with the rock; others may be present as the ash from the coal or coke used in mixed-feed vertical kilns. Because of the chemical reactions in progress in this zone between the charge and the brick, the surfaces of the latter approach a plastic state. This makes resistance to the abrasion of the descending load in vertical kilns of importance.

In vertical kilns, zone No. 3 also includes the firebox arches, kiln eyes, and a height



Courtesy of Allis-Chalmers Manufacturing Co.

FIG. 2.—Rotary Kiln and Cooler for Lime Burning.

Kiln proper	10 ft. in diameter by 150 ft. in length
Rotary cooler	7 ft. in diameter by 73 ft. in length

up to 5 to 10 ft. above the eyes. At these points resistance to spalling, due to the shrinkage of the refractory under heat and to temperature changes during firing, as well as to pinching in arches improperly laid, becomes an important property. The arches at the eyes frequently carry the load of the superstructure of the kiln, and the brick accordingly should have good load-carrying capacity when heated.

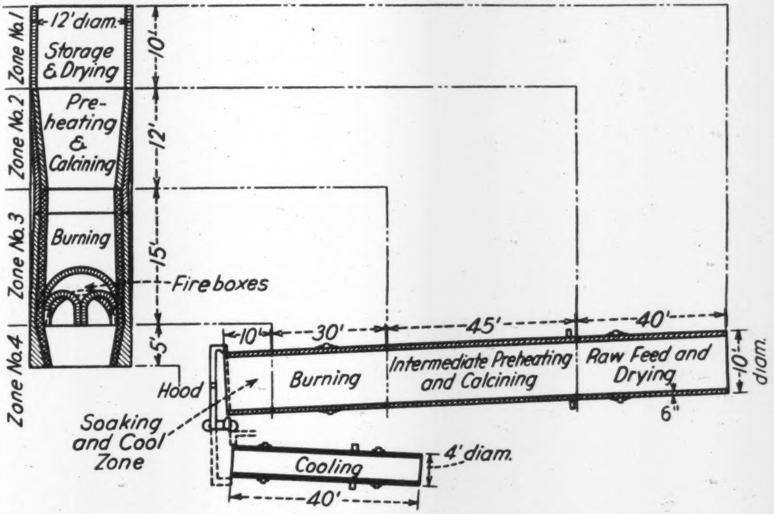

Zone No.1
12' diam.
Storage & Drying
10'
Zone No.2
Pre-heating & Calcining
12'
Zone No.3
Burning
15'
Fireboxes
Zone No.4
5'
Hood
Soaking and Cool Zone
10'
30'
45'
40'
Burning
Intermediate Preheating and Calcining
Raw Feed and Drying
10' diam.
6"
4' diam.
Cooling
40'

FIG. 3.—Typical Zones of Vertical and Rotary Lime Kilns with Similar Refractory Requirements.

TABLE I.—CLASSIFICATION OF REFRACTORIES FOR LIME BURNING.

Furnace part	Material	Temperature[a]	Slagging action	Spalling	Abrasion	Load	Remarks
Zone 1.....	Moderate and intermediate heat duty fireclay brick	Outdoor to 800 F. (425 C.)	None	Unimportant	Severe	Unimportant	Hard, dense fire brick, frequently used in vertical kilns.
Zone 2.....	High heat duty fireclay brick	1000 to 1700 F. (540 to 925 C.)	None	Unimportant	Important	Unimportant	
Zone 3.....	Super duty and high heat duty fireclay brick, high alumina brick, silica brick	Vertical kilns: 1500 to 2400 F. (815 to to 1315 C.) Rotary kilns: Max. temp. may reach 2600 F. (1425 C.)	Severe at points of maximum	Moderate to severe	Important	Important in vertical kilns only	Burned and unburned magnesite brick are sometimes used for extremely severe service in rotaries. Spalling may be severe in firebox arches of vertical kilns.
Zone 4.....	High heat duty fireclay brick	Vertical kilns: 1800 to 100 F. (980 to 38 C.) Rotary kilns: 1800 to 1200 F. (980 to 650 C.)	None	Slight to severe	Important	Unimportant	Spalling may be severe in nose blocks of rotaries, or in vertical following shutdowns.
Rotary cooler....	High heat duty and intermediate duty fireclay brick	1200 to 100 F. (650 to 38 C.)	None	Slight to moderate	Important	None	

[a] The equivalent Centigrade temperatures given in parentheses are to the nearest five degrees.

Conditions in the burning zone of rotary kilns are frequently more severe than those in vertical kilns. Most rotary kilns do not readily pick up a protective coating in the burning zone, and since (in those producing primary lime) the particles are much smaller than in vertical kilns, there is a tendency for the reaction between the lime and the lining to proceed at a faster rate. In rotary kilns producing secondary lime reclaimed from certain processing residues, as in the paper and sugar industries, an appreciable amount of alkalies, which readily attack aluminum silicates at kiln temperatures is present. Accordingly, many high-alumina bricks are used for the burning zone of both primary and recovery lime kilns. Magnesite brick are also frequently used in burning zones of recovery lime kilns.

Zone No. 4, which is the discharge end of both types of kilns, is not a zone of unusual severity. The lime charge is still hot, however, and spalling is to be guarded against, particularly in the case of the nose blocks of rotary kilns.

Rotary Cooler (used only in conjunction with rotary kilns).—Except for a moderate amount of abrasion, no significant refractories problems are likely to be met in the rotary cooler.

Table I gives a classification of requirements for refractories for lime burning.

APPENDIX II

INDUSTRIAL SURVEY OF CONDITIONS SURROUNDING REFRACTORY SERVICE IN CONTINUOUS PLATE GLASS AND WINDOW GLASS FURNACES

The portion of the glass industry engaged in producing plate glass and window glass is commonly termed the "flat glass" industry. Plate glass is mechanically ground and polished flat glass. Window glass is fire-finished flat glass. In general, both are soda-lime glasses and the melting procedures are similar. Continuous furnaces of many designs are used for melting these glasses. These designs depend largely upon the type of forming or drawing process employed. The continuous tank considered in this survey is suited in design for a plate glass blank rolling machine or a Colburn window glass machine. American manufacturers usually operate a tank furnace for the production of plate or of window glass, not both. Modern plate glass machines roll a sheet at much faster speeds than window glass machines draw a sheet. Consequently, plate glass furnace operating temperatures and daily tonnages are much higher. The temperatures given in the body of this survey are average for plate glass furnace operation, whereas those given in Table I cover the range from low window glass to high plate glass tank operation.

The term "tank furnace" designates a type of furnace in which the lower portion acts as a container in which the raw batch is melted and the glass refined. The separately supported upper portion, consisting of side walls, and walls and crown, confines combustion directly above the glass. The burner-port openings are either in the end or side walls of the upper portion, depending upon the furnace design. This survey is confined to the side-port type of furnace. The fuel is natural gas. In describing the various furnace parts, reference will be made to the specific dimensions given in the furnace drawings shown in Figs. 1 to 3, but it should be understood that furnace dimensions vary considerably, depending upon tonnage, depth, type of fuel, and structural features.

FURNACE PARTS

Melting Chamber or Melter.—The melting chamber (Fig. 1) is rectangular in shape, 62 by 21 ft., and has a depth of 5 ft. The block, called flux block, used to build the melting chamber are either highly siliceous clay or high alumina types. These may take the form of hand made, machine made, or slip cast block, but the high alumina type is also made by casting molten material into molds to produce so-called electrocast block. Clay blocks 12 in. in thickness are usually used for the bottom. In a 5-ft. depth tank, the side wall has one or more horizontal joints. Therefore, the courses generally consist of a 24 by 36-in. block and a 24 by 24-in. block, or two 24 by 30-in. blocks. These blocks are 12 in. in thickness when of the clay type, and 8 in. or less in thickness when of the electrocast type. Sometimes five 12-in. courses are used. The average melting chamber temperature is about 2790 F. (1530 C.),[1] but some furnaces maintain higher temperatures ranging up to about 3000 F. (1650 C.) The purpose of this chamber is to bring about complete fusion and solution of the glass batch before it passes through the neck into the refining chamber.

Refining Chamber or Refiner.—The refining chamber (Fig. 1) has the same depth and shape as the melting chamber. It is 24 by 16 ft. It is built of the same type block as the melting chamber. Clay blocks are more common in this part of a furnace. Refining chambers may vary considerably in shape and size, depending upon the type

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[1] The equivalent Centigrade temperatures given in parentheses in this survey are to the nearest five degrees.

TABLE I.—CLASSIFICATION OF REFRACTORIES FOR FLAT GLASS INDUSTRY.

Furnace Parts	Material	Temperature	Slagging action	Abrasion	Spalling	Remarks
Melting chamber: Bottom Sides Ends	Highly siliceous hand made, machine-made or slip-cast block. High-alumina molten cast block	2450 to 3000 F. (1345 to 1650 C.)	Severe	Severe	Slight	Spalling is of great importance during heating up
Doghouse: Bottom Sides	Same as melting chamber	Up to 2900 F. (1595 C.)	Severe	Severe	Slight	Same as melting chamber
Refining chamber: Bottom Sides Ends	Same as melting chamber	Up to 2850 F. (1565 C.)	Severe in some furnaces	Slight	Slight	Same as melting chamber
Neck: Bottom Side	Same as melting chamber	Up to 3000 F. (1650 C.)	Severe	Moderate	Slight	Same as melting chamber
Tank crown	Silica brick	Up to 3000 F. (1650 C.)	Moderate to severe	Severe in some furnaces	Important	
End walls	Silica brick. High-alumina block	Up to 3000 F. (1650 C.)	Moderate to severe	Severe in some furnaces	Unimportant	
Breast walls and Plate Block	Silica block. High-alumina block. Molten cast block	Up to 3000 F. (1650 C.)	Severe	Severe	Slight	Spalling of plate block very important when replaced during hot repair
Invert arches	Silica shapes	Up to 3000 F. (1650 C.)	Severe	Severe	Important	
Port jambs	Silica block. High-alumina block. Molten cast block	Up to 3000 F. (1650 C.)	Severe	Severe	Slight	
Port sills (Plate block)	Silica block. High-alumina block. Molten cast block	Up to 3000 F. (1650 C.)	Severe	Severe	Slight	Same as plate block
Burner block	Fireclay block. High-alumina block	Up to 3000 F. (1650 C.)	Severe	Severe	Important	Same as plate block
Port snouts: Crown Sides Paving	High heat duty fireclay brick. High-alumina brick	Up to 3000 F. (1650 C.)	Severe	Severe	Slight	
Port chambers: Crown Sides Paving	High heat duty fireclay brick. High-alumina brick	Up to 3000 F. (1650 C.)	Severe	Severe	Slight	
Uptakes	High heat duty fireclay brick. High-alumina brick	Up to 2900 F. (1595 C.)	Severe	Severe	Slight	
Regenerator chamber: Crowns Walls	High heat duty fireclay brick	2500 F. (1370 C.) max.	Severe in upper portion; slight in lower portion	Severe in upper portion	Important	Some limited use of high-alumina brick in crowns
Checkers	High heat duty fireclay brick. Super duty fireclay brick	2550 F. (1400 C.) max.	Same as for regenerator chamber	Severe in upper portion	Important	Some use of special magnesite brick

TABLE I.—*Continued*

Furnace Parts	Material	Temperature	Slagging action	Abrasion	Spalling	Remarks
Tunnels (canals)	Intermediate heat-duty fireclay brick	Up to 1400 F. (760 C.)	Unimportant	Unimportant	None	
Stack	Intermediate and moderate heat duty fireclay brick	Up to 1350 F. (735 C.)	Unimportant	Unimportant	None	
Tuckstones	Silica shapes. High-alumina shapes. Molten cast shapes	Up to 3000 F. (1650 C.)	Severe	Severe	Slight	Watercoolers sometimes replace Tuckstones
Cooling chamber: Bottom Sides	Same as melting chamber	Up to 2650 F. (1455 C.)	Moderate to severe	Moderate	Important	
Superstructure	Silica brick and shapes	Up to 2650 F. (1455 C.)	Slight	None	Important	
Floaters	Siliceous clay parts, handmade and slip cast	Up to 2650 F. (1455 C.)	Moderate to severe	Unimportant	Important	Requires good transverse strength

of sheet-forming machine used and the number of machines being fed by it. The average temperature of 2535 F. (1390 C.) is maintained solely by radiation, conduction, and convection of heat from the melting chamber because no burner ports open directly into it. The temperature in some refining chambers may be as high as 2850 F. (1565 C.). The purpose of this chamber is to permit the refining, or plaining, of the molten glass before it passes on through the cooling chamber to the forming machine.

Neck.—The neck (Fig. 1) is the connecting chamber between the melting and refining chambers. It is 8 ft. in length by 10 ft. in width by 5 ft. in depth. By comparison in sectional area with the two chambers it joins, it is a considerable restriction to the flow of both the glass and the combustion products from the melting to the refining chamber. The neck may or may not be built of the same type block as the adjacent chambers. The practice varies somewhat between plate glass and window glass furnaces. The thickness of block is usually 12 in. regardless of type because of the greater wear experienced.

Doghouse.—As shown in Figs. 1 and 3, the doghouse is a small vestibule opening into the center of the rear end wall of the melting chamber. All of the batch fed to the furnace passes through it. A furnace may have one, two, or more doghouses depending upon the size of the furnace and the means of feeding the batch. Mechanical batch feeders, if used, generally determine the design or completely eliminate this part of a furnace. Since the doghouse is one of the points of severest attack in the furnace, it is usually built of special block and, even then, of greater thickness than 12 in.

Regenerators and Checker Brick.—Figures 1 and 2 show the gas and air regenerators which parallel both sides of the melting chamber. The furnace under consideration is fired with natural gas; therefore, both generators are used for air and the gas is admitted at the burner block. This is not uncommon practice because otherwise, natural gas will crack and plug the checker chambers. The regenerator chambers may vary considerably in dimensions. They are filled completely with a mass of open brickwork called "checkers." Regular 9-in. fireclay brick, 2½ by 4½ by 13½-in. brick, and 3 by 6 by 18-in. tile of the super duty and high heat duty types are used to construct checkers. The size of the chambers and the number of courses of checker brick depend upon the size of the melting chamber and the fuel used. If producer gas is used as fuel, the inside chamber is always the gas chamber.

The preheating of air for combustion is essential for obtaining the high flame temperatures required in glass melting. In

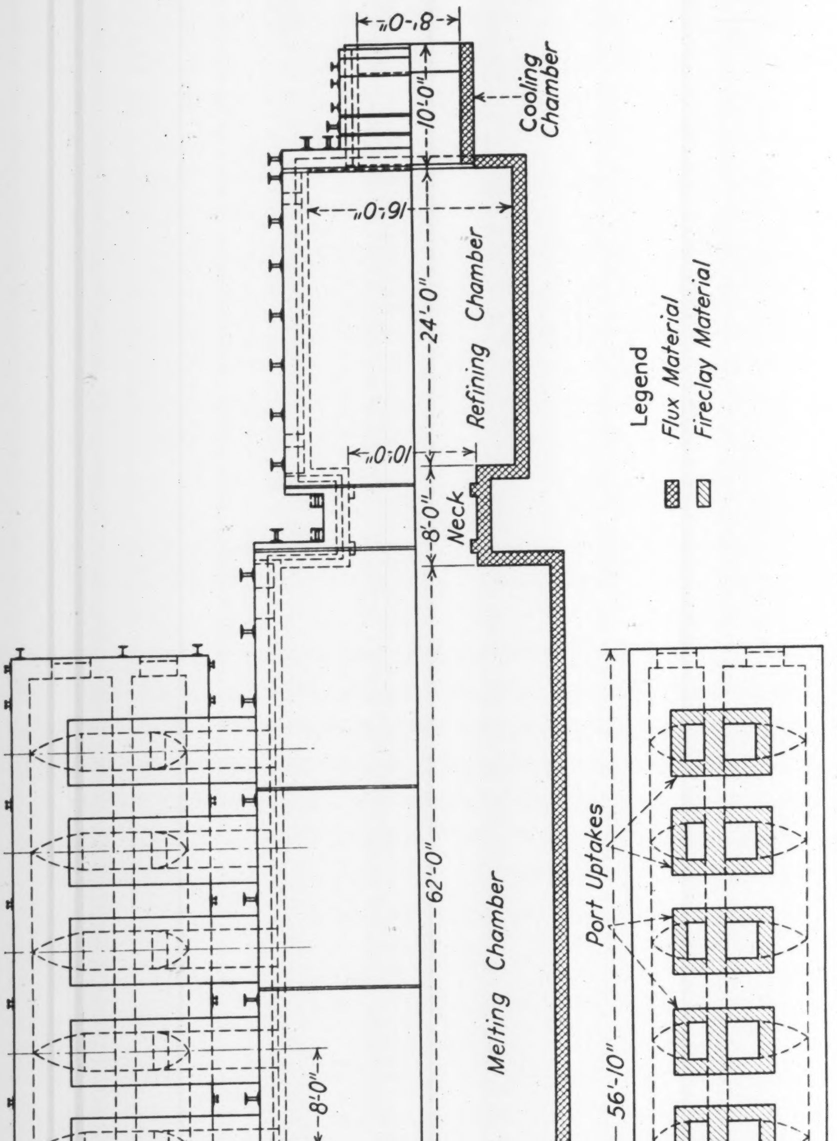
8'-0"
10'-0"
Cooling Chamber
16'-0"
24'-0"
Refining Chamber
10'-0"
8'-0"
Neck
Legend
Flux Material
Fireclay Material
62'-0"
Melting Chamber
Port Uptakes
56'-10"
8'-0"
8'-0"
21'-0"
4'-0"
Doghouse
16'-5"
15'-4"

FIG. 1.—Regenerative Type Glass Furnace, Sectional Plan.

order to accomplish this, the combustion products and other hot gases pass from the melting chamber by way of the ports down through the checker chambers on one side of the furnace to the tunnels (canals), and out the stack. These outgoing gases heat up the top courses of checker brick to a usual temperature of about 2100 F. (1150 C.), with 2550 F. (1400 C.) as a maximum, which tapers off to around 1350 F. (735 C.) in the bottom courses. Meanwhile, air for combustion is retracing the path of the outgoing gases through the set of checkers on the opposite side of the furnace. By reversing the flow of hot gases and air through the two sets of checkers at regular intervals, generally 20 to 30 min., the high temperature preheat of the air is obtained and maintained.

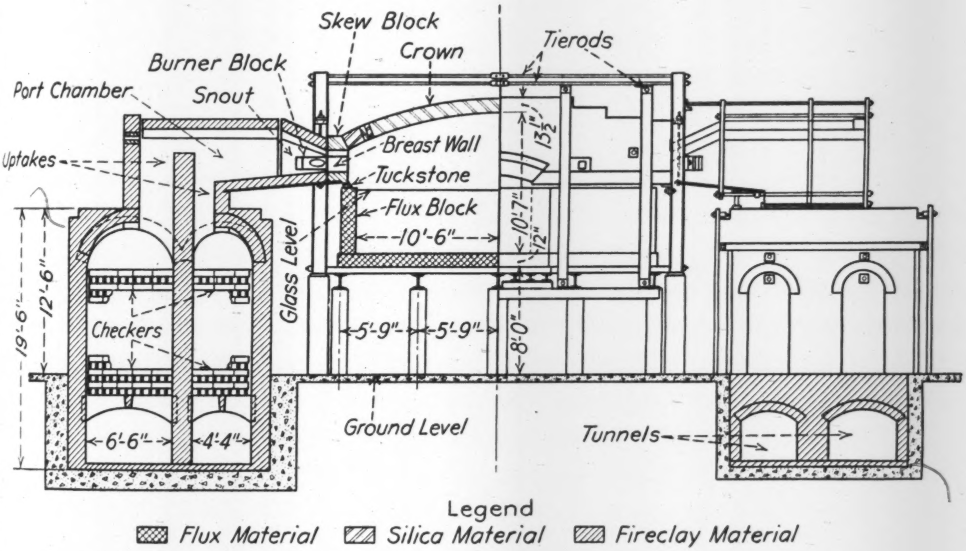

FIG. 2.—Regenerative Type Glass Furnace, Half Section on Center Line of First Port.

Ordinarily the regenerator chamber walls, which are 18 to 23 in. in thickness, and the checkers are built entirely of high heat duty fireclay brick. Super duty fireclay brick and special magnesite brick, however, are sometimes used to a limited extent for the top courses of checkers.

Burner Ports.—The port assembly, as shown in Figs. 1 and 2, consists of a snout, a port chamber, two burner blocks and two uptakes. The number of ports on a furnace varies according to size of the furnace. The furnace under consideration is a six-port furnace, meaning six ports on each side of the melting chamber. The uptakes are short vertical chimneys built on top of the regenerator crowns and connecting the horizontal port chamber with the regenerator chambers. The division wall between the two checker chambers is continued up to form a division wall or bridge wall between the two air uptakes. This wall ends about midway of the port chamber. If producer gas is used, the wall is turned and continued as a horizontal division wall, termed tongue arch, to the snout. The short, tapered end of the port chamber is called the snout and connects the port chamber with the port opening. The port openings are located in the melting chamber breast walls. It is through these port openings that the air and gas enter and the combustion products leave the furnace. A burner block is set in each side wall of the snout. They aim the gas stream through the port opening into the furnace. Therefore, combustion begins in the port opening. The entire port assembly is built of at least high heat

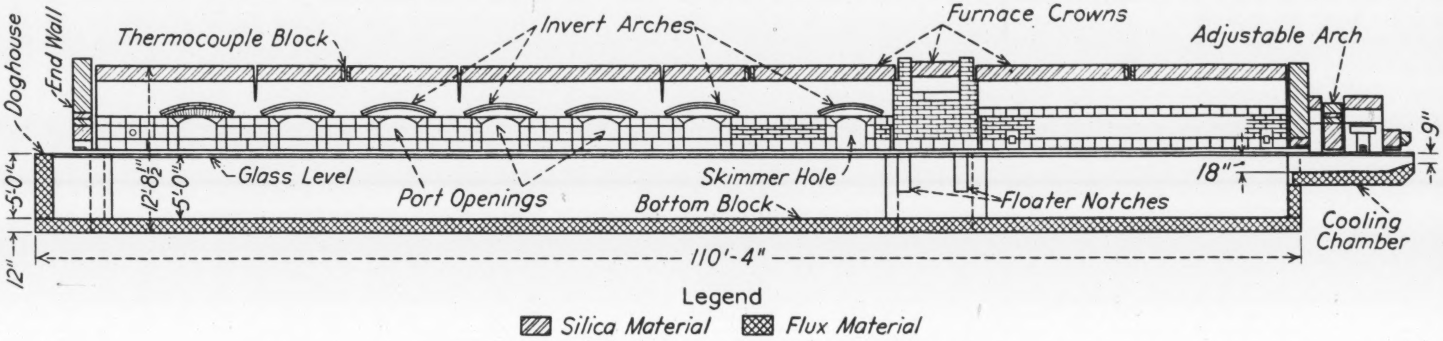
Doghouse
End Wall
Thermocouple Block
Invert Arches
Furnace Crowns
Adjustable Arch
9"
18"
Glass Level
Port Openings
Skimmer Hole
Bottom Block
Floater Notches
Cooling Chamber
5'-0"
12'-8½"
5'-0"
12"
110'-4"
Legend
Silica Material
Flux Material

FIG. 3.—Regenerative Type Glass Furnace, Longitudinal Section.

duty fireclay brick and shapes. The major portion of all batch dust and volatilized batch ingredients is carried by the outgoing gases into the several ports nearest the doghouse or rear end wall. Because of this, it is rather common practice to line these ports partially or totally with special high alumina brick and shapes.

Crown, Side and End Walls.—The crowns, side and end walls (Figs. 2 and 3)[1] comprise the upper portion of the furnace. This entire superstructure is supported by steel work at a level just above the top of the flux block. The flux blocks, therefore, do not support a load other than their own. Since the superstructure generally outlasts two or more replacements of flux block, the horizontal separation of the upper and lower portions of the furnace is essential. The side and end walls are built well back of the inside face of the flux block. These walls are 18 in. in thickness and generally constructed of silica brick or block. For reasons mentioned under ports, a portion of the breast walls including jamb and sill block of the port openings nearest the rear end wall is often built of special high alumina or electrocast material. The crowns, or caps, of the neck and of the melting and refining chambers are built entirely of silica brick and usually laid up dry. Invert arches in the crown protect the port openings by distributing the thrust lengthwise to the skew block.

Tuckstones.—Tuckstones are small brick of triangular or trapezoidal section used to seal the horizontal joint between the top of the flux block and the bottom of the side and end walls. They are merely placed on top of the flux block. A combination of high alumina and silica tuckstones is general practice. Water coolers are sometimes used instead of tuckstones.

Cooling Chamber.—The cooling chamber (Figs. 1 and 3) is an 8 by 10-ft. chamber of varying depth which supplies the forming machine with glass from the refining chamber. It is a type of forehearth. It also serves as a conditioning chamber for the molten glass preparatory to forming the sheet. The adjustable curtain arch and side wall burner openings permit control of the conditioning. The depth of glass in the cooling chamber is 18 in. throughout except for the sloping bottom block at the machine end of the chamber, which reduces the glass depth to 7 in. The type of furnace considered here has only one machine but larger furnaces have two machines. Each sheet drawing process has a forehearth designed to suit it, and with some processes, the number of drawing machines operated from one tank furnace may vary from one to ten or twelve. The bottom and side walls of the cooling chamber are constructed of flux block, usually the siliceous clay type. The superstructure is built entirely of silica brick and shapes. From the standpoint of glass quality produced, forehearth refractories are very important. Sloughed refractory particles make stones in the sheet, and rapid solution of the flux block produces heterogeneous glass. The average temperature is around 2425 F. (1330 C.), and the maximum about 2650 F. (1455 C.).

Floaters.—Floaters are movable dams, generally made of two or three interlocking pieces. One or two dams may be placed in the neck. Such a dam affects the convection currents in the molten glass and tends to prevent the passage of floating impurities into the refining chamber. Suitable notches in the flux block side walls anchor the floaters. As the dam actually floats almost completely submerged in the glass, the depth of immersion depends upon the design of the floaters. Wherever possible, the glass manufacturer makes his own floaters. Highly siliceous clay is favored. Dams are far more common in window glass furnaces than in plate glass furnaces but by no means absolutely essential to either. Floaters are replaced often. Debiteuse and skimmer block are, in general, similar to floaters.

COOLING

The artificial cooling of tank furnaces by air and water is essential. Provisions for cooling are part of the furnace design and are many and varied. Some manufacturers prefer air cooling, others prefer water cooling.

No mortar of any kind is used in setting flux block, therefore, trueness of dimension is important in permitting close fitting joints. The cooling effect of the outside air circulation about the furnace is to solidify the glass in the joints, thereby preventing leakage. The cooling requirements increase with the age of the furnace. Water jackets are practically always used at points of severest attack, such as the metal line, doghouse and neck corners, regardless of the general method of cooling employed. Emergency fans are kept ready at each furnace to concentrate cooling on any place that may require it.

INSULATION

The application of insulation to the tank furnace in the flat glass industry is hardly beyond the experimental stage except in the case of forehearths. With some forming processes, insulation of the forehearths has long been practiced. The insulation of regenerator chambers naturally leads in number of applications being tried. Standard insulating brick are probably most favored. The insulation of uptakes, port side walls, and main furnace crowns is being tried in some plants. The trend toward insulating tank furnaces, in part at least, is definitely growing.

REFRACTORY LIFE

Since regular furnace life may vary from less than 1 to more than 3 yr., depending upon the many factors involved, a statement on average service life of the various refractories used would be misleading. The variable factors are furnace design and size, composition of the glass batch, daily tonnage melted, fuel used, and furnace operation. Comparative calculations on furnace life are of little value unless all figures and factors involved are known. Rarely, if ever, are two campaigns on a single furnace the same. Some portion of the refractories in the furnace will serve two, three, or more campaigns. The accompanying Table I classifies the requirements of refractories used in the flat glass industry. The extent of the destructive influences under the several headings of Table I is based upon the maximum temperatures as stated. Load requirements of the various refractories used are not important enough to be listed.

REPORT OF COMMITTEE C-9

ON

CONCRETE AND CONCRETE AGGREGATES

Committee C-9 on Concrete and Concrete Aggregates held three meetings during the year: one in Washington, D. C., on November 29, 1938; one in Columbus, Ohio, on March 8, 1939; and one during the annual meeting of the Society in Atlantic City, N. J.

The following papers are being presented in appendices to this report:

"A Statistical Analysis of Compression Tests on Mortar Cylinders, Cubes, and Prisms," by H. W. Leavitt and H. A. Pratt, submitted by Subcommittee XI on Evaluation of Data,[1]

"Some Observations of the Water Vapor Permeability of Concrete," by H. J. Barre, submitted by Subcommittee VIII on Permeability Tests of Concrete, and[2]

"Methods for Measuring the Passage of Water Through Concrete," by W. M. Dunagan, submitted by Subcommittee VIII on Permeability Tests of Concrete.[3]

During the year Committee C-9 established, with the approval of the Society, "The Sanford E. Thompson Award," as an annual token of recognition to the author or authors of a paper of outstanding merit on concrete or concrete aggregates presented at an annual meeting of the Society. The award is named in honor of the first chairman of Committee C-9. The purposes are to stimulate research, encourage the presentation of results of investigations that extend the knowledge of concrete and concrete aggregates, and to recognize meritorious effort. The award is $50 and a suitable certificate or certificates. The rules governing the award are presented as Appendix III to this report.

Subsequent to the 1938 annual meeting, Committee C-9 presented to the Society through Committee E-10 on Standards the following recommendations which were accepted[4] by Committee E-10 on August 25, 1938, and appear in the 1938 *Proceedings*:[5]

Tentative Method of Test for Clay Lumps in Aggregates (C 142 - 38 T), Revision of Tentative Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 37 T), joint recommendation with Committee D-4 on Road and Paving Materials,

Tentative revision of Standard Method of Test for Unit Weight of Aggregate for Concrete (C 29 - 27), in the form of a new tentative method (C 29 - 38 T), and

Tentative revision of Standard Method of Test for Structural Strength of Fine Aggregate Using Constant-Water-Cement-Ratio Mortar (C 87 - 36).

On the recommendation of Subcommittee IX on Specifications and Methods of Tests of Aggregates (H. F. Clemmer, chairman) the committee is presenting the following proposed methods for publication as information:

Proposed Method of Test for Soundness of Aggregates by Use of Magnesium Sulfate:[6]

This method was formulated by C. E.

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[1] See p. 851.

[2] See p. 860.

[3] See p. 866.

[4] In submitting these recommendations to Committee E-10 on Standards, Committee C-9 reported the following results of the letter ballot vote of a total of 37 ballots returned from a committee membership of 61: C 142 - 38 T and C 131 - 38 T, affirmative 36, negative 0, ballots marked "not voting" 1; C 29 - 38 T, affirmative 35, negative 2; C 87 - 36, affirmative 37, negative 0.

[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 806, 803, 817, 1325, (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 632, 629, 657, 1691.

[6] See p. 885.

Wuerpel in an effort to overcome difficulties encountered in the existing Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 - 37 T). A paper by Mr. Wuerpel in support of the proposed method appears as an appendix to this report.[7]

Proposed Method of Test for Organic Impurities in Sand by pH Value:[8]

This method was developed by Ira Paul in response to a need for a test method which would aid in evaluating fine aggregates. A paper by Mr. Paul in support of the proposed method appears as an appendix to this report.[9]

I. REVISION OF TENTATIVE STANDARD

The Committee recommends that the Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 - 37 T)[10] be revised as follows, as proposed by Subcommittee IX on Specifications and Methods of Tests of Aggregates (H. F. Clemmer, chairman) and continued as tentative:

Section 1.—Change the last three sentences from their present form to read as follows:

> In selecting aggregates, consideration should be given to service records of the materials when exposed to actual weathering conditions over a period of at least 5 yr., but, in the absence of such information, the test method should be used as the basis of acceptance or rejection of the material. Either or both of these methods may be used. However, attention is called to the fact that the test results by the use of the two methods differ considerably and care must be exercised in fixing proper limits in any specifications which may include requirements for these tests.

Section 2 (c).—Change this section from its present form to read as follows:

> (*c*) *Containers.*—Containers for immersing the samples of aggregate in the solution, in accordance with the procedure hereinafter described, shall be perforated in such a manner as to permit of free access of the solution to the sample and of drainage of the solution from the sample without loss of aggregate. The volume of the solution in which samples are immersed shall be at least five times the volume of the sample immersed at any one time.
>
> NOTE.—Baskets made of suitable wire mesh or sieves with suitable openings are satisfactory containers for the samples.

II. REVISIONS OF STANDARDS

The committee recommends for immediate adoption, revisions in the following methods of test, proposed by Subcommittee VII on Methods and Apparatus for Testing Concrete (A. T. Goldbeck, chairman), and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society:

Standard Method of Making and Storing Compression Test Specimens of Concrete in the Field (C 31 - 38):[11]

The revisions have been incorporated in the revised methods appended hereto.[12]

Standard Methods of Making Compression Tests of Concrete (C 39 - 33):[13]

Section 3.—Omit the fifth sentence, which reads as follows:

> Aggregates shall be in a room-dry condition when used in concrete tests.

Add the following at the end of this section:

> Aggregates shall be brought to an approximately saturated condition, containing surface

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[7] Charles E. Wuerpel, "Modified Procedure for Testing Concrete Aggregate Soundness by Use of Magnesium Sulfate," p. 882.

[8] See p. 898.

[9] Ira Paul, "New Laboratory Method for Determining the Organic Matter in Washed Fine Aggregates," p. 892.

[10] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 804 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 645.

[11] 1938 Supplement to Book of A.S.T.M. Standards, p. 114.

[12] This method was adopted as standard by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part II.

[13] 1936 Book of A.S.T.M. Standards, Part II, p. 342.

moisture in sufficiently small amounts to preclude loss by draining. The amounts of surface moisture on the coarse and fine aggregates shall be determined, prior to making concrete specimens, in accordance with the Tentative Method of Test for Specific Gravity and Absorption of Fine Aggregate (A.S.T.M. Designation: C 128) and the Tentative Method of Test for Specific Gravity and Absorption of Coarse Aggregate (A.S.T.M. Designation: C 127) of the American Society for Testing Materials.

Sections 5 and 6.—At the end of these sections add new Paragraphs (*f*) and (*d*), respectively, to read as follows:

(*f*) Test for specific gravity and absorption made in accordance with the Tentative Method of Test for Specific Gravity and Absorption of Fine Aggregate (A.S.T.M. Designation: C 128).

(*d*) Test for specific gravity and absorption made in accordance with the Tentative Method of Test for Specific Gravity and Absorption of Coarse Aggregate (A.S.T.M. Designation: C 127).

Section 10.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

10. Concrete shall be mixed by hand in batches of such size as to leave a small quantity of concrete after molding a single test specimen *or a series of identical test specimens to be tested at different ages.* The batch shall preferably be mixed in a shallow *water-tight, clean,* metal pan, with [a 10-in.] *either a blunted* bricklayer's trowel [which has been blunted by cutting off about 2½ in. of the point, as follows] *or a shovel, whichever is most convenient, using the following procedure:*

Section 11.—Change from its present form to read as follows:

11. (*a*) *Consistency.*—The consistency of each batch of concrete shall be measured immediately after mixing by one of the following methods: (*1*) Slump test made in accordance with the Tentative Method of Test for Consistency of Portland-Cement Concrete (A.S.T.M. Designation: D 138), or (*2*) Flow test made in accordance with the Tentative Method of Test for Flow of Portland-Cement Concrete by Use of the Flow Table (A.S.T.M. Designation: C 124).

(*b*) *Yield.*—The yield of each batch of concrete shall be determined in accordance with the Tentative Method of Test for Yield of Concrete (A.S.T.M. Designation: C 138).

Section 14.—Change from its present form to read as follows:

14. (*a*) Two to four hours after molding, the test specimens, if made in metal molds, may be capped with a thin cap of neat-cement paste. The cap shall be formed by means of a piece of plate glass ¼ in. in thickness or a machined metal plate ½ in. in thickness and of a diameter 2 or 3 in. larger than that of the mold. The plate shall be worked on the cement paste until the plate rests on top of the mold. The cement for capping should be mixed to a stiff paste 2 to 4 hr. before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the concrete to the top and bottom plates may be avoided by coating them with heavy oil or grease.

(*b*) If specimens are not capped with neat-cement paste, they shall be capped before testing in such a manner that the ends are perfectly plane and at right angles to the axis of the cylinder. The material used for capping and the thickness of the cap shall be such that it will not flow or fracture under the load.

NOTE.—It is desirable that the capping material have a value for modulus of elasticity equal to or greater than that of the concrete.

Section 20.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

20. The load shall be applied [uniformly and] without shock. The moving head of the *screw type of* testing machine shall travel at the rate of about 0.05 in. per min. when the machine is running idle. *In hydraulic machines the loading shall be adjusted to a constant rate within the limits of 35 ± 15 psi. per sec.*

Section 24 (*e*).—Change to read as follows by the addition of the italicized word and the omission of the words in brackets:

(*e*) The method of measuring [workability or plasticity] *consistency* with "slump" or "flow" of concrete;

Standard Methods of Securing Specimens of Hardened Concrete from the Structure (C 42 - 31):[14]

Section 6.—At the end of this section add a note to read as follows:

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[14] 1936 Book of A.S.T.M. Standards, Part II, p. 351.

NOTE.—It is desirable that the capping material have a value for modulus of elasticity equal to or greater than that of the concrete.

Section 7.—A minor editorial rearrangement will be made in the table of strength correction factors. Following the table add a sentence to read as follows:

The specimen shall be measured for height after it has been capped.

Section 8.—Change the last sentence to read as follows by the addition of the italicized words and the omission of those in brackets:

In order that the tests *may* be made under uniform conditions as to moisture content, the test specimens shall be completely submerged in water *at room temperature* for *24 to* 48 hr. [and the compression test shall be made immediately thereafter] *immediately prior to the compression test.*

Standard Method of Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam With Third Point Loading) (C 78 – 38):[15]

Section 2 (c).—Omit the first sentence which reads as follows:

Aggregates shall be in a room-dry condition when used in concrete tests.

At the end of this section add two new sentences to read as follows:

Aggregates shall be brought to an approximately saturated condition, containing surface moisture in sufficiently small amounts to preclude loss by draining. The amounts of surface moisture on the coarse and fine aggregates shall be determined prior to making concrete specimens, in accordance with the Tentative Method of Test for Specific Gravity and Absorption of Fine Aggregate (A.S.T.M. Designation: C 128) and the Tentative Method of Test for Specific Gravity and Absorption of Coarse Aggregate (A.S.T.M. Designation: C 127).

Section 9 (a).—Change from its present form: namely,

9. (*a*) The following minimum cross-sections shall be used for the flexure test specimens:

Size of Coarse Aggregate, In.	Width, In.	Depth, In.
1½	6	6
2 and 2½	8	6

to read as follows:

9. (*a*) The cross-section of the test specimen shall be 6 by 6 in.

Section 11.—Change this section from its present form to read as follows:

11. (*a*) *Consistency.*—The consistency of each batch of concrete shall be measured immediately after mixing by one of the following methods: (*1*) Slump test made in accordance with the Tentative Method of Test for Consistency of Portland-Cement Concrete (A.S.T.M. Designation: D 138), or (*2*) Flow test made in accordance with the Standard Method of Test for Flow of Portland-Cement Concrete by Use of the Flow Table (A.S.T.M. Designation: C 124).

(*b*) *Yield.*—The yield of each batch of concrete shall be determined in accordance with the Tentative Method of Test for Yield of Concrete (A.S.T.M. Designation: C 138).

Section 18.—Change the first part of the first sentence from "The specimen with the molded top up, . . ." to read "The specimen with its molded side up, . . ."

Section 19.—Change the eighth line of Paragraph (*a*) from "The specific gravity" to read "The specific gravity and absorption."

Change Paragraph (*d*) to read as follows by the addition of the italicized word:

(*d*) The consistency, slump, or *flow* of each batch of concrete.

Standard Method of Making Compression Tests of Concrete Using Portions of Beams Broken in Flexure (C 116 – 36):[16]

Section 1.—Change to read as follows by the omission of the words in brackets:

1. This method is intended to cover compression tests of concrete using for the test speci-

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[15] 1938 Supplement to Book of A.S.T.M. Standards, p. 119.

[16] 1936 Book of A.S.T.M. Standards, Part II, p. 348.

> mens portions of beams broken in flexure [in accordance with the Standard Laboratory Method of Making Flexure Tests of Concrete Using a Simple Beam with Third Point Loading (A.S.T.M. Designation: C 78) of the American Society for Testing Materials, or portions of beams having a square cross-section molded and tested in accordance with other recognized methods].

Section 3.—Change the first two sentences to read as follows by the addition of the italicized words and the omission of those in brackets:

> 3. [If the sides of the beam as cast consist of plane, smooth surfaces accurate to 0.005 in., no capping will be necessary. If the sides of the beam as cast are not true planes they] *The top and bottom of the beam* shall be capped in such a manner that plane surfaces are secured [on opposite sides of the beam as cast].

Add the following sentence at the end of this section:

> During the interval between testing of specimens as beams and testing the broken portions as cubes, the specimens shall be kept moist by storage in a moist closet or under wet burlap.

Section 5.—Change from its present form: namely,

> 5. The load shall be applied uniformly and without shock. The rate of application of load shall be not in excess of that applied by a testing machine, the moving head of which under no load travels at the rate of 0.05 in. per min.

to read as follows:

> 5. The load shall be applied without shock. The moving head of the screw type of testing machine shall travel at the rate of about 0.05 in. per min. when the machine is running idle. In hydraulic machines the loading shall be adjusted to a constant rate within the limits of 35 ± 15 psi. per sec.

Standard Method of Test for Flow of Portland-Cement Concrete by Use of the Flow Table (C 124 – 38):[17]

Section 3.—Change this section from its present form to read as follows:

> 3. Samples of concrete for test specimens shall be taken at the mixer, or in the case of ready-mixed concrete, from the transportation vehicle during discharge. The sample of concrete from which test specimens are made shall be representative of the entire batch. Such samples shall be obtained by repeatedly passing a scoop or pail through the discharging stream of concrete, starting the sampling operation at the beginning of discharge and repeating the operation until the entire batch is discharged. The sample thus obtained shall be transported to the place of molding of the specimen and to counteract segregation the concrete shall be mixed with a shovel until it is uniform in appearance. The location in the work of the batch of concrete thus sampled, shall be noted for future reference. In the case of paving concrete, samples may be taken from the batch immediately after depositing on the subgrade. At least five samples shall be taken from different portions of the pile and these samples shall be thoroughly mixed to form the test specimen.

Section 4.—Change the next to the last sentence to read as follows by the addition of the italicized figure and the omission of the figure in brackets:

> The table shall then be raised and dropped ½ in., 15 times in about [10] *15* sec.

III. Adoption of Tentative Standards as Standard

The committee recommends that the following tentative standards be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Specifications for:

- Concrete Aggregates (C 33 – 37 T),[18]
- Lightweight Aggregate for Concrete (C 130 – 37 T),[18]

Tentative Methods of Test for:

- Coal and Lignite in Sand (C 123 – 36 T),[19]
- Specific Gravity and Absorption of Coarse Aggregate (C 127 – 36 T),[19]
- Specific Gravity and Absorption of Fine Aggregate (C 128 – 36 T),[19] with an editorial revision in Section 2 (*b*) changing the calibration of the 500-ml. flask from "0.1 ml." to "0.15 ml."

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[17] 1938 Supplement to Book of A.S.T.M. Standards, p. 124.

[18] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, pp. 792, 798 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 620, 626.

[19] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, pp. 794, 805, 808, 811 (1936); also 1938 Book of A.S.T.M. Tentative Standards, pp. 634, 651, 654, 662.

Sieve Analysis of Fine and Coarse Aggregates (C 136 – 38 T),[20]
Yield of Concrete (C 138 – 38 T),[20]
Clay Lumps in Aggregate (C 142 – 38 T),[20] and
Tentative Definitions of Terms Relating to Concrete and Concrete Aggregates (C 125 – 36 T),[19] definitions for "admixture," "crushed stone," "fineness modulus," and "gravel."

The committee recommends that the following two tentative methods be approved for reference to letter ballot of the Society for adoption as standard with revisions as indicated below:

Tentative Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 – 38 T),[20] revisions proposed by Subcommittee IX on Specifications and Methods of Tests of Aggregates (H. F. Clemmer, chairman), joint recommendation of Committee C-9 and Committee D-4 on Road and Paving Materials:

Section 2.—Change the sixth sentence to read as follows by the addition of the italicized words:

> The cover shall be so designed as to maintain the cylindrical contour of the interior surface *unless the shelf is so located that the charge will not fall on the cover, or come in contact with it during the test.*

Section 3 (b).—Change the Note to this section from its present form: namely,

> Note.—The limiting weight for each cast-iron or steel sphere permits the use of a charge consisting of a mixture of steel balls $1\frac{7}{8}$ in. and $1\frac{13}{16}$ in. in diameter. When steel spheres heavier than the prescribed weights are obtained, it is suggested that they be reduced in size by grinding. Cast-iron spheres, uniform in size, meeting these specifications are readily available.

to read as follows:

> Note.—Steel spheres $1\frac{27}{32}$ in. in diameter and weighing 417 g. can be obtained from at least one manufacturer. If they are not readily available the next larger size ($1\frac{7}{8}$ in.) may be ground to size. Cast-iron spheres, uniform in size, meeting these specifications are available.

Tentative Method of Test for Consistency of Portland-Cement Concrete (D 138 – 32 T),[21] revisions proposed by Subcommittee VII on Methods and Apparatus for Testing Concrete (A. T. Goldbeck, chairman):

Section 3.—Change this section from its present form to read the same as Section 3 of Standard Method C 124 as recommended above.

Section 4.—Change the first sentence to read as follows by the addition of the italicized words:

> *The mold shall be dampened and placed on a flat, moist, non-absorbent surface. From the sample of concrete obtained as previously described,* the mold shall *immediately* be filled in three layers, each approximately one-third the volume of the mold.

Section 5.—Add a note at the end of this section to read as follows:

> Note.—After the slump measurement is completed, the side of the concrete frustrum should be tapped gently with the tamping rod. The behavior of the concrete under this treatment is a valuable indication of the cohesiveness, workability, and placeability of the mix. A well proportioned workable mix will gradually slump to lower elevations and retain its original identity, while a poor mix will crumble, segregate, and fall apart.

IV. Adoption as Standard of Tentative Revisions of Standards

The committee recommends that the tentative revisions[22] of the following two standards which were accepted for publication in August, 1938, through Committee E-10 on Standards, be adopted as standard and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society:

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[20] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I. pp. 808, 819, 806, 803 (1938); also 1938 Book of A.S.T.M, Tentative Standards, pp. 636, 659, 632, 629.

[21] *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part I, p. 775 (1932); also 1938 Book of A.S.T.M. Tentative Standards, p. 935.

[22] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1325, 817 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1691, 657.

Standard Method of Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (C 87 - 36), and

Standard Method of Test for Unit Weight of Aggregate for Concrete (C 29 - 27), in the form of Tentative Method of Test for Unit Weight of Aggregate (C 29 - 38 T), with a further revision proposed by Subcommittee IX on Specifications and Methods of Tests of Aggregate (H. F. Clemmer, chairman), as follows:

Section 5.—Add a center heading before this section to read "Compact Weight Determination."

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF TENTATIVE STANDARD			
Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 - 37 T)	42	0	5
II. REVISIONS OF STANDARDS (For Immediate Adoption)			
Making and Storing Compression Test Specimens of Concrete in the Field (C 31 - 38)	44	2	1
Making Compression Tests of Concrete (C 39 - 33)	43	2	2
Securing Specimens of Hardened Concrete from the Structure (C 42 - 31)	43	2	1
Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third Point Loading) (C 78 - 38)	41	0	6
Making Compression Tests of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method) (C 116 - 36)	41	1	5
Test for Flow of Portland-Cement Concrete by Use of the Flow Table (C 124 - 38)	44	1	2
III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for Concrete Aggregate (C 33 - 37 T)	44	0	2
Spec. for Lightweight Aggregate for Concrete (C 130 - 37 T)	38	0	8
Test for Coal and Lignite in Sand (C 123 - 36 T)	42	1	4
Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 36 T)	44	0	2
Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 36 T)	42	1	3
Test for Sieve Analysis of Fine and Coarse Aggregates (C 136 - 38 T)	45	0	1
Test for Yield of Concrete (C 138 - 38 T)	45	0	1
Test for Clay Lumps in Aggregate (C 142 - 38 T)	42	1	3
Definitions of Terms Relating to Concrete and Concrete Aggregates (C 125 - 36 T), four definitions	34	1	2
Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 38 T), as revised	41	1	5
Test for Consistency of Portland-Cement Concrete (D 138 - 32 T), as revised	46	0	1
IV. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (C 87 - 36)	38	2	7
Test for Unit Weight of Aggregate for Concrete (C 29 - 27)	45	1	1

Section 6.—Change to read as follows by the addition of the italicized words:

6. The jigging method is applicable to aggregates having a maximum size greater than 2 in. *and not to exceed 4 in.*

New Section.—Add a new Section 7 covering Loose Weight Determination to read as follows, renumbering the present Section 7 as Section 8:

7. This method is applicable to aggregates having a maximum size of 4 in. or less. The measure shall be filled to overflowing by means of a shovel or scoop, the aggregate being discharged from a height of not to exceed 2 in. about the top of the measure. Care shall be taken to prevent, so far as possible, segregation of the particle sizes of which the sample is composed. The surface of the aggregate shall then be leveled off with the fingers or a straight edge in such a way that any slight projections of the larger pieces of the coarse aggregate

shall balance the larger voids in the surface below the top of the measure.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 68 members, with the results shown in Table I.

This report has been submitted to letter ballot of the committee which consists of 68 members; 44 members returned their ballots, of whom 43 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

F. H. JACKSON,
Chairman.

R. R. LITEHISER,
Secretary.

APPENDIX

RULES GOVERNING THE SANFORD E. THOMPSON AWARD

Sponsored by Committee C-9 on Concrete and Concrete Aggregates

The Sanford E. Thompson Award was established in 1938 by Committee C-9 on Concrete and Concrete Aggregates of the American Society for Testing Materials as an annual token of recognition to the author or authors of a paper of outstanding merit on concrete or concrete aggregates presented at an annual meeting of the Society. The award is named in honor of the first chairman of the committee. The purposes are to stimulate research, encourage the presentation of results of investigations that extend the knowledge of concrete and concrete aggregates, and to recognize meritorious efforts.

1. The Advisory Committee of Committee C-9 shall appoint annually at its fall meeting a Committee on Award, consisting of three members of Committee C-9. Members of the Society's Committee E-6 on Papers and Publications of the Society shall not serve as members of the Award Committee.

2. The Committee on Award shall review the eligible papers on concrete and concrete aggregates presented at the preceding annual meeting of the Society. Papers to be eligible for the award shall be the *bona fide* production of those who contribute them and shall not have been previously made public nor contributed elsewhere. Papers duly accepted by the Committee on Papers and Publications for presentation at the preceding annual meeting, including papers accepted for publication as appendices to the report of the committee, shall be eligible.

3. The Committee on Award shall advise the Advisory Committee of Committee C-9 not later than the spring meeting of Committee C-9 of the paper selected for the award. The person or persons so selected to receive the award and the Executive Committee of the Society shall be notified by the Advisory Committee.

4. The award shall be made at a session on concrete held during the annual meeting of the Society following that at which the selected paper was presented.

5. When in the opinion of the Committee on Award, none of the papers is worthy of the award, no award shall be made for that year.

6. The award shall be Fifty Dollars ($50) and a suitable certificate or certificates. Funds for the award shall be provided by Committee C-9.

7. The Advisory Committee of Committee C-9 shall have authority to decide any questions not specifically covered by these rules, and to make such modifications thereof as it may deem desirable.

REPORT OF COMMITTEE C-11
ON
GYPSUM

Committee C-11 on Gypsum has held one meeting during the past year, at the National Bureau of Standards in Washington, D. C., on April 12, 1939.

Activities of Subcommittees

Subcommittee II on Gypsum Plasters (J. M. Porter, chairman), and Subcommittee IV on Testing Methods (C. K. Roos, chairman).—These two subcommittees, working together, have been particularly active in the review of Specifications for Keene's Cement (C 61 – 30) and for Gypsum Plasters (C 28 – 30). In addition to the tentative revisions in these standards which were made last year, some of which are now recommended for adoption as standard, several additional revisions are being recommended, as mentioned later in this report.

I. Revisions of Standards

Standard Methods of Testing Gypsum and Gypsum Products (C 26 – 33).[1]—The Standard Specifications for Gypsum Plasters (C 28 – 30) specify not less than 1 per cent by weight of wood fiber in wood-fibered plaster. However, there is no method for the determination of the wood fiber content included in the Standard Methods of Testing Gypsum and Gypsum Products (C 26 – 33). The National Bureau of Standards has suggested two methods: an elutriation method, and an ammonium acetate method. These methods have been checked by several members of Subcommittees II and IV, and both methods were found to be reasonably accurate. The elutriation method, however, is simpler and quicker. Committee C-11 accordingly presents for publication as tentative, the following revision of Methods C 26:

New Section.—Add the following section for determining wood fiber content in wood-fibered gypsum plaster as a new Section 34, renumbering the subsequent sections accordingly:

> 34. Determination of Wood Fiber Content in Wood-Fibered Gypsum Plaster.—A 100-g. sample of wood-fibered plaster, as prepared in Section 1, shall be placed on a No. 30 (590-micron) sieve nested over a No. 100 (149-micron) sieve. The plaster on the No. 30 sieve shall then be washed with a stream of cold water, removing the No. 30 sieve when the fiber on it is practically or entirely free of plaster. The material on the No. 100 sieve shall next be washed until the bulk of the plaster has been washed through the sieve and the residue is mainly fiber. The material retained on the No. 100 sieve shall then be transferred to a 3-qt. vitreous enamel lipped pan, adding the charge on the No. 30 sieve if the fiber contains any adhering particles of plaster. The material in the pan shall then be elutriated (purified by washing and straining; effecting as clean a separation of fiber from plaster as is feasible) catching the elutriated fibers on a No. 100 sieve. To avoid loss of the fine particles of fiber, it may be necessary to make the transfer from the pan to the No. 100 sieve by several stages of washing, stirring the charge, and quickly pouring upon the sieve the fiber flotations, repeating the elutriation procedure several times. The fiber collected on the No. 100 sieve shall then be examined, and the elutriation shall be repeated if it seems desirable.

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[1] 1936 Book of A.S.T.M. Standards, Part II, p. 106.

The sieves (or sieve, as the case may be) with the residue contained therein shall then be dried overnight in an oven maintained at a temperature of 45 C. The sieves, or sieve, shall then be carefully inverted over a piece of white paper, and the residual material transferred to the paper by brushing the bottom of the inverted sieve. The transferred material shall then be examined visually, noting whether the separation of fibers from plaster has been complete. The material shall then be transferred to a weighed platinum crucible and dried to constant weight at a temperature of 45 C. If the previous visual examination of the charge on the white paper showed that the fiber was practically free of particles of plaster, the weight of the fiber dried at 45 C., divided by 100, corresponds to the percentage of fiber. If, on the other hand, the visual examination revealed the presence of an appreciable quantity of plaster associated with the fiber, the contents of the crucible shall be ignited carefully to constant weight. The loss on ignition, divided by 100, shall, in this case, correspond to the percentage of fiber.

Standard Definitions of Terms Relating to the Gypsum Industry (*C 11 – 28*).[2]—Inasmuch as the Standard Specifications for Gypsum Plastering Sand were withdrawn several years ago, and as there are now Tentative Specifications for Sand for Use in Plaster (C 35 – 36 T) which contain a definition for sand, the committee recommends the immediate omission from Definitions C 11 – 28 of the definition given below. The committee accordingly asks for the necessary nine-tenths vote at the annual meeting in order that this modification may be referred to letter ballot of the Society:

> *Gypsum Plastering Sand.*—The fine granular material naturally or artificially produced by the disintegration of rock, containing not less than 80 per cent by weight of silica, feldspar, dolomite, magnesite or calcite.

II. ADOPTION OF TENTATIVE STANDARD AS STANDARD

Tentative Specifications for Sand for Use in Plaster (*C 35 – 36 T*).[3]—The committee recommends that these specifications, which are under the joint jurisdiction of Committee C-7 on Lime and Committee C-11, be approved for reference to letter ballot of the Society for adoption as standard with the following revision. Committee C-7 concurs in this recommendation.[4]

Section 2.—Add a new Paragraph (*b*) to read as follows, relettering the present Paragraph (*b*) as (*c*):

> (*b*) The amount of material finer than a No. 200 (74-micron) sieve, shall not exceed 5 per cent.

Section 3.—Omit this section which reads as follows, renumbering the subsequent sections accordingly:

> 3. The amount of deleterious substances, including material finer than a No. 200 sieve, shall not exceed 5 per cent.

Section 5 (*b*).—Change the heading "Deleterious Substances" to read "Material Finer than No. 200 Sieve."

III. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

Standard Specifications for Gypsum Plasters (*C 28 – 30; A.S.A. A49.3–1933*).[5]—Section 15 of these specifications specifies that retarded gaging plaster shall set in not less than 40 min. nor more than 6 hr. Gaging plaster is frequently retarded to set in more than 6 hr. and there is no reason why it should set in less than 6 hr.

The tensile strength of the scratch or first coat of gypsum ready-sanded plaster, according to Section 4 of these specifications, shall be not less than 75 psi., and the browning or second coat not less than 50 psi. It has long been felt that these tensile strength requirements are too low and in accordance with tests conducted at the National Bureau of Standards, it is recommended that these minimum requirements be increased.

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[2] 1936 Book of A.S.T.M. Standards, Part II, p. 117.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 771 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 505.

[4] See p. 336.

[5] 1936 Book of A.S.T.M. Standards, Part II, p. 89.

The committee accordingly recommends that the revision of Specifications C 28 published as tentative last year[6] be further revised as indicated below, and approved for reference to letter ballot of the Society for adoption as standard:

Section 4.—Change Paragraphs (*a*) and (*b*) to read as follows by the addition of the italicized figures and the omission of the words and figures in brackets:

(*a*) Scratch or First Coat.—This plaster shall have a tensile strength of not less than [75 psi. (5¼ kg. per sq. cm.)] *125 psi.*

(*b*) Browning or Second Coat.—This plaster shall have a tensile strength of not less than [50 psi. (3½ kg. per sq. cm.)] *75 psi.*

Section 8.—Change to read as follows by the addition of the italicized figures and the omission of the words and figures in brackets:

8. Gypsum neat plaster as tested with two parts of standard Ottawa sand shall have a tensile strength of not less than [75 psi. (5¼ kg. per sq. cm.)] *125 psi.*

Section 15.—Change to read as follows by the omission of the words in brackets:

15. Calcined gypsum for finishing coat when not retarded shall set in not less than 20 min. nor more than 40 min., and when retarded shall set in not less than 40 min. [nor more than 6 hr.]

Standard Methods of Testing Gypsum and Gypsum Products (*C 26 – 33*).[7]—The committee recommends that the revision of Methods C 26 published as tentative last year[6] be approved for reference to letter ballot of the Society for adoption as standard, with a minor modification in Section 22. The second sentence of this section requires that the gypsum be cast in a five-gang briquet mold and since there is no reason why it should be a five-gang any more than a three-gang or single mold, it is recommended that the following change be made:

Section 22.—Change the second sentence to read as follows by the omission of the words in brackets:

Cast in a [five-gang] briquet mold of the shape and size shown in Fig. 2.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF STANDARDS			
Testing Gypsum and Gypsum Products (C 26 – 33)	16	0	4
Definitions of Terms Relating to the Gypsum Industry (C 11 – 28), immediate adoption	17	1	2
II. ADOPTION OF TENTATIVE STANDARD AS STANDARD			
Spec. for Sand for Use in Plaster (C 35 – 36 T), as revised	18	0	2
III. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Spec. for Gypsum Plasters (C 28 – 30; A.S.A. A49.3-1933)	17	0	3
Testing Gypsum and Gypsum Products (C 26 – 33)	17	0	3

IV. STANDARDS CONTINUED WITHOUT REVISION

The committee has reviewed the following standards, which have stood for at least six years without revision, and while it has no recommendations to make at this time it is continuing its review of these specifications and expects to recommend changes next year:

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[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1322 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1688.

[7] 1936 Book of A.S.T.M. Standards, Part II, p. 106.

Standard Specifications for:

- Gypsum (C 22 – 25),
- Calcined Gypsum for Use in the Preparation of Dental Plasters (C 72 – 30),
- Gypsum Partition Tile or Block (C 52 – 33),
- Gypsum Molding Plaster (C 59 – 30), and
- Gypsum Pottery Plaster (C 60 – 30).

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 22 members; 20 members returned their ballots, with the results shown in Table I.

This report has been submitted to letter ballot of the committee which consists of 22 members; 20 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. S. Wells,
Chairman.

H. J. Schweim,
Secretary.

REPORT OF SECTIONAL COMMITTEE

ON

SPECIFICATIONS FOR PLASTERING

ASA Project: A42

Sectional Committee A42 on Specifications for Plastering held no meetings during the past year but has been active through correspondence and conference. The work of the committee has included:

1. The completion of Standard Specifications for Gypsum Plastering Including Requirements for Lathing and Furring. This standard was transmitted to the sponsors (American Society for Testing Materials and American Institute of Architects) under date of May 27, 1938, and was approved as American standard on September 29, 1938, being assigned the ASA designation A42.1—1938. The widespread distribution and use of the standard is very gratifying. Over 30,000 copies have been printed to date.

2. Subsequent to consideration at a meeting held May 25, 1938, a revised draft of a proposed Standard Specification for Portland-Cement Stucco and Portland-Cement Plaster was distributed and balloted upon. Following certain criticisms and suggestions received during the ballot, a third draft (February 15, 1939) was prepared and another ballot has been taken. Transmittal of this proposed standard to the sponsors is deferred pending further consideration of the objections offered by the negative voters.

3. Informal conferences have taken place concerning the preparation of the following additional standards: (1) lime plaster and lime stucco, (2) cement-lime or lime-cement stucco, and (3) masonry-cement stucco. Committee A42 proposes ultimately to undertake the preparation of a single master standard which will include the separate standards now prepared and being prepared.

The changes in the personnel of the committee are as follows:

Arthur Bohnen replaced W. C. Miller as the representative of the National Association of Real Estate Boards.

J. W. Stockett, Jr., replaced S. Walter Stauffer as the representative of the National Lime Association.

Respectfully submitted on behalf of the committee,

Walter R. McCornack,
Chairman.

J. W. McBurney,
Secretary.

REPORT OF COMMITTEE C-12

ON

MORTARS FOR UNIT MASONRY

Committee C-12 on Mortars for Unit Masonry has held three meetings during the past year: in Atlantic City, N. J., on June 29, 1938; in Washington, D. C., on November 2, 1938; and in Columbus, Ohio, on March 10, 1939.

As this is the first formal report of Committee C-12 since its reorganization in November, 1937, some discussion of personnel may, therefore, be appropriate. The committee was reorganized with 23 members, of whom 11 were classified as producers, 3 as consumers, and 9 as general interest members. The membership at present totals 35, of whom 16 are classified as producers, 8 as consumers, and 11 as general interest members.

The following subcommittees have been established:

I, Advisory (J. W. McBurney, chairman),
II on Methods of Test (A. T. Goldbeck, chairman),
III on Specifications for Mortar (Theodore Irving Coe, chairman), and
IV on Specifications for Aggregates for Mortar (Stanton Walker, chairman).

In addition, two working subcommittees have been formed to consider the subjects of Workability and Plasticity of Mortar, and Soundness and Volume Change of Mortar.

These several subcommittees have been quite active. During the year Subcommittee II presented a report on "A Preliminary Consideration of Some Proposed Methods of Sampling and Testing Mortar for Unit Masonry," which was published as information in the ASTM *Bulletin*.[1]

Subcommittee III presented a draft of proposed Specifications for Mortar for Unit Masonry at the November, 1938, meeting of Committee C-12, and at the March, 1939, meeting offered a revised draft of these specifications. A letter ballot was taken on the proposal to publish this second draft together with a "Primer on Specifications and Tests for Masonry Mortars," prepared by Subcommittee III in collaboration with Subcommittee II as appendices to the annual report for information. This ballot resulted in a vote of 23 affirmative, 6 negative, and 1 ballot marked "not voting." However, at the meeting of the committee held in Atlantic City, N. J., on June 28, 1939, it was voted to refer the specifications and primer back to Subcommittee III. The vote was 17 affirmative, 8 negative, and 4 "not voting." These two documents will accordingly receive further consideration by the subcommittee before publication.

Subcommittee III is sponsoring a coöperative series of tests on masonry cement and cement-lime mortars which is being carried on by members of this committee and other interested coöperating laboratories. The response to date has been very gratifying.

Subcommittee IV prepared and presented a report on "Aggregate for Masonry Mortar" including proposed specifications which have been published in the ASTM *Bulletin*.[2] These specifications are being recommended for publication as tentative, as indicated below.

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[1] ASTM BULLETIN, No. 94, October, 1938, p. 40.

NEW TENTATIVE STANDARD

The committee recommends for publication, new Tentative Specifications for Aggregate for Masonry Mortar.[3] The considerations governing the preparation of these specifications are presented in detail in the report of Subcommittee IV.[2]

This recommendation has been submitted to letter ballot of the committee which consists of 35 members; 24 members returned their ballots, all of whom have voted affirmatively.

This report has been submitted to letter ballot of the committee which consists of 35 members, 28 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. W. MCBURNEY,
Chairman.

H. C. PLUMMER,
Secretary.

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[2] ASTM BULLETIN, No. 97, March, 1939, p. 34.

[3] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

REPORT OF COMMITTEE C-13

ON

CONCRETE PIPE

Committee C-13 on Concrete Pipe held a meeting in Chicago, Ill., on May 2, 1938, for the primary purpose of revising the Tentative Specifications for Concrete Irrigation Pipe (C 118 - 35 T). The action of the committee in this connection was reported to the Society at the 1938 annual meeting,[1] and as a result the revised Tentative Specifications for Concrete Irrigation Pipe (C 118 - 38 T)[2] were accepted for publication.

The committee has received no criticisms of the provisions of these tentative specifications. On the other hand, the committee has been reliably informed that the specifications are considered acceptable in their present form by manufacturers and practicing engineers in the irrigation regions of this country.

The committee accordingly recommends that the Tentative Specifications for Concrete Irrigation Pipe (C 118 - 38 T)[2] be approved for reference to letter ballot of the Society for adoption as standard. This recommendation has been submitted to letter ballot of the committee which consists of 26 members; 26 members returned their ballots, of whom 25 have voted affirmatively, 1 negatively, and 0 members marked their ballots "not voting."

This report has been submitted to letter ballot of the committee which consists of 26 members; 26 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

THEODORE DOLL,
Chairman.

M. W. LOVING,
Secretary.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 355 (1938).

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 796 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 610.

REPORT OF COMMITTEE C-14

ON

GLASS AND GLASS PRODUCTS

Committee C-14 on Glass and Glass Products held one meeting during the year, in Atlantic City, N. J., on June 29, 1938, during the annual meeting of the Society.

Most of the six subcommittees have been active. Consideration is being given to the preparation of tentative standards and to the development of fundamental information on which such standards are based. The following four test methods have now been developed which, after approval by Committee C-14, will be presented to the Society during the summer through Committee E-10 on Standards for publication as tentative (see Editorial Note):

Methods of:
- Chemical Analysis of Glass Sand,
- Hydrostatic Pressure Test of Glass Containers,
- Polariscopic Examination of Glass Containers, and
- Thermal Shock Test on Glass Containers.

Respectfully submitted on behalf of the committee,

G. W. Morey,
Chairman.

Louis Navias,
Secretary.

Editorial Note

Subsequent to the annual meeting Committee C-14 on Glass and Glass Products presented to the Society through Committee E-10 on Standards the following recommendations:

Proposed Tentative Methods of:
- Chemical Analysis of Glass Sand (C 146 – 39 T),
- Hydrostatic Pressure Test of Glass Containers (C 147 – 39 T),
- Polariscopic Examination of Glass Containers (C 148 – 39 T), and
- Thermal Shock Test of Glass Containers (C 149 – 39 T).

These new tentative methods were accepted by Committee E-10 on August 24, 1939, assigned the A.S.T.M. serial designations indicated above, and appear in the 1939 Book of A.S.T.M. Standards, Part II.

REPORT OF COMMITTEE C-15 ON MANUFACTURED MASONRY UNITS

Committee C-15 on Manufactured Masonry Units held three meetings during the year: one in Atlantic City, N. J., on June 28, 1938, during the annual meeting of the Society, one in Washington, D. C., on November 1, 1938, and the third in Columbus, Ohio, on March 9, 1939. The committee has been active, but some of the important proposals considered were referred to the subcommittees concerned pending the completion of current investigations.

During the year all of the standards of the committee were revised for the purpose of making them alike as to form and phraseology in so far as that was feasible in view of the differences in composition, properties, and structure of the products. As these revisions did not result in material changes in substance, they are not included in the list of recommendations affecting standards.

In appreciation of his invaluable service to Committee C-15 since its organization and of his able direction of the activities of the former Committee C-3 on Brick from 1923 to 1930, Professor T. R. Lawson has been unanimously elected honorary chairman.

I. New Tentative Standard

The committee recommends that the proposed Tentative Specifications for Solid Load-Bearing Concrete Masonry Units be accepted for publication as tentative.[1] These specifications apply to units having less than 25 per cent cell space and intended for use in load-bearing masonry, especially in masonry requiring greater strength or fire resistance than would normally be obtained with hollow units.

II. Revisions of Tentative Standards

The committee recommends that the following three tentative specifications[2] be revised, as indicated below, and continued as tentative:

Tentative Specifications for Sewer Brick (Made from Clay or Shale) (C 32 – 37 T):[3]

Section 2 (a).—In the footnote to the table of requirements for physical properties, change the term "C/B ratio" to read "saturation coefficient (C/B)."

Tentative Specifications for Building Brick (Made from Clay or Shale) (C 62 – 37 T):[3]

Section 2.—In the third column of the table of requirements for physical properties and in the footnote to the table in Paragraph (*a*), and in Paragraph (*c*), change the terms "C/B ratio" and "ratio C/B" to read "saturation coefficient (C/B)."

Tentative Specifications for Glazed Building Units (C 126 – 37 T):

Section 9 (b).—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

(*b*) The [ratio of the absorption by 24-hr. submersion in water to the absorption by 5-hr. submersion in boiling water] *saturation coefficient* (*C/B*) shall not exceed 0.80.

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[1] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, pp. 749, 733, 736 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 532, 514, 519

[3] See Editorial Note, p. 379.

III. REVISIONS OF STANDARDS

The committee recommends for immediate adoption, revisions in two standards, as indicated below, and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society:

Standard Methods of Testing Brick (C 67 – 37):[3,4]

Section 16 (*b*).—Add a note to this section to read as follows:

NOTE.—Storage of brick, unstacked, with separate placement, in a ventilated room for a period of 4 hr., with a current of air from an electric fan passing over them for a period of at least 2 hr., will cool the specimens to approximately room temperature. Specimens noticeably warm to the touch should not be used for the absorption test.

Section 22.—In this section change the terms "absorption ratio," "C/B ratio," and "absorption ratio (C/B)" to read "saturation coefficient (C/B)."

Standard Specifications and Tests for Load-Bearing Concrete Masonry Units (C 90 – 36):[5]

Sections 10 to 25.—These sections covering methods of testing are substantially the same as the Tentative Methods of Sampling and Testing Concrete Masonry Units (C 140 – 38 T). In the interest of economy in publication, it is recommended that Sections 10 to 25 be replaced by a section referring to Methods C 140.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Spec. for Solid Load-Bearing Concrete Masonry Units	34	0	10
II. REVISIONS OF TENTATIVE STANDARDS			
Spec. for Sewer Brick (Made from Clay or Shale) (C 32 – 37 T)	41	1	7
Spec. for Building Brick (Made from Clay or Shale) (C 62 – 37 T)	41	1	7
Spec. for Glazed Building Units (C 126 – 37 T)	41	1	7
III. REVISIONS OF STANDARDS			
Methods of Testing Brick (C 67 – 37), immediate adoption	42	0	7
Spec. and Tests for Load-Bearing Concrete Masonry Units (C 90 – 36), immediate adoption	34	0	9
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Sampling and Testing Concrete Masonry Units (C 140 – 38 T)	34	0	9
Spec. for Sand-Lime Building Brick (C 73 – 38 T)	34	0	15
Spec. for Concrete Masonry Units for Use in the Construction of Catch Basins and Manholes (C 139 – 38 T)	29	0	15
Spec. for Hollow Non-Load-Bearing Concrete Masonry Units (C 129 – 38 T), as revised	34	0	10
Spec. for Structural Clay Load-Bearing Wall Tile (C 34 – 38 T), as revised	37	1	2
V. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD			
Spec. for Structural Clay Non-Load-Bearing Title (C 56 – 36)	38	0	2
Spec. for Structural Clay Floor Title (C 57 – 36)	38	0	2

In addition, changes are being made in the specifications[6] so that they will conform in phraseology with the other specifications under the jurisdiction of the committee.

IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following five tentative standards[7] be approved for reference to letter ballot of the Society for adoption as standard,

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[4] 1937 Supplement to Book of A.S.T.M. Standards, p. 78.

[5] 1936 Book of A.S.T.M. Standards, Part II, p. 168.

[6] These specifications were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 787, 777, 785, 783, 779 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 543, 517, 541, 539, 535.

with a revision in two specifications as indicated below:

Tentative Methods of Sampling and Testing Concrete Masonry Units (C 140 – 38 T),

Tentative Specifications for Sand-Lime Building Brick (C 73 – 38 T),

Tentative Specifications for Concrete Masonry Units for Use in the Construction of Catch Basins and Manholes (C 139 – 38 T), and

Tentative Specifications for Hollow Non-Load-Bearing Concrete Masonry Units (C 129 – 38 T), revised as follows:

Section 5 (a).—Change to read as follows by the omission of the sentence in brackets:

5. *(a)* [Units shall contain no materials which will stain plaster applied thereto.] The combustible content present in cinder aggregate shall not exceed 35 per cent of the weight of the aggregate.

Tentative Specifications for Structural Clay Load-Bearing Wall Tile (C 34 – 38 T), revised as follows to replace the Standard Specifications C 34 – 36:

Section 4 (c).—Add the following sentence to this section:

If no cell in side construction tile, measured in the direction of the wall thickness, exceeds four times the average over-all thickness of either the upper or lower bearing shells, the requirements for minimum shell and web thickness specified in Paragraph 4 *(b)* shall be waived.

V. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD

The committee recommends that the tentative revisions of the following two standards which were submitted for publication as tentative last year[8] be approved for reference to letter ballot of the Society for adoption as standard:

Standard Specifications for Structural Clay Non-Load-Bearing Tile (C 56 – 36),[9] and

Standard Specifications for Structural Clay Floor Tile (C 57 – 36).[9]

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 52 members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Clay Building Brick (J. W. McBurney, chairman).—Proposed revisions of the Tentative Specifications for Building Brick (Made from Clay or Shale) (C 62 – 37 T) were prepared and considered by the committee. The purpose of one of these was to permit the acceptance of products which have shown satisfactory performance in freezing-and-thawing tests, even though they do not comply with all of the physical requirements of the standard. Although most brick which failed to meet the physical requirements of the standard are not highly resistant to frost action, a few which do not conform have an excellent record in service as well as in laboratory weathering tests. Because of objections to the form of the proposed revision, the question was referred to the subcommittee for further study.[3]

The subcommittee also gave consideration to the development of a method of testing bricks to determine their tendency to be a source of efflorescence on masonry. Bearing on this subject is a paper by J. M. Hardesty on "Disintegration of Face Brick by Crystallization of Soluble Salt," appended[10] to this report.

Subcommittee III on Concrete Units (W. G. Kaiser, chairman).—During the preparation of the proposed Tentative Specifications for Solid Load-Bearing Concrete Masonry Units, the subcommittee reviewed available data on the properties of commercial products and their performance in service and in laboratory tests. These data indicated the desirability of making the requirements more rigid than those of existing specifications. The minimum average strength requirements of 1200 and 1800 psi. for grades A and B, respectively, of the proposed specifications reflect the conclusions based on this study.

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[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1324, 1325 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1690, 1691.

[9] 1936 Book of A.S.T.M. Standards, Part II, pp. 176, 179.

[10] See p. 971.

The Tentative Specifications for Hollow Non-Load-Bearing Concrete Masonry Units (C 129 - 38 T), now recommended for adoption, have been available for criticism for two years without substantial change in the technical requirements. Similarly, no criticisms have been received of the Tentative Specifications for Concrete Masonry Units for Use in the Construction of Catch Basins and Manholes (C 139 - 38 T) and these also are recommended for adoption as standard. Revisions of other standards relating to concrete units were necessary because of the separation of the specification requirements from the methods of testing.

Subcommittee IV on Sand-Lime Brick (C. H. Carmichael, chairman).—As no suggestions for revising the Tentative Specifications for Sand-Lime Building Brick (C 73 - 38 T) have been received during the year, the specifications are recommended for adoption as standard.

Subcommittee V on Paving Brick (F. H. Jackson, chairman).—The subcommittee is following closely the cooperative investigation of the properties and performance of paving brick being carried out by the U. S. Bureau of Public Roads and the Ohio State Highway Commission. Pending the completion of this investigation, the committee does not expect to prepare revisions of the existing specifications.

Subcommittee VI on Sewer Brick (T. R. Lawson, chairman).—Twice during the year the committee has approved a revision of the requirements for sewer brick. Each time, however, the criticisms received on letter ballot have indicated the need for further consideration of the proposed revision.

Subcommittee VII on Glazed Brick and Tile (J. R. Kauffman, chairman).—This subcommittee prepared a program for an investigation of the properties of glazed units. At present the program is being considered by representatives of the industries concerned.

Subcommittee VIII on Structural Clay Tile (H. C. Plummer, chairman).—The proposed revisions of the standards relating to structural clay tile have, for the most part, met with favor by both the industry and the consumers. However, the limitation on shell thickness of side construction tile seems to be unduly severe when applied to small units. Methods of overcoming this objection are now being studied.

Working Committee on Investigation of Methods of Capping Structural Clay Tile.—The investigation on methods of capping structural clay tile carried out at Rensselaer Polytechnic Institute under the direction of T. R. Lawson, has been completed but the results are not as yet assembled for publication.

Working Committee on Modular Sizes (Frederick Heath, Jr., chairman).—A Sectional Committee on Coordination of Dimensions of Building Materials and Equipment (A 62) has now been organized under the procedure of the American Standards Association to study the broad problem of formulating dimensions for all types of building materials. Close contact will be maintained with this project since the Society has appointed a representative on the sectional committee from Committee C-15.

This report has been submitted to letter ballot of the committee which consists of 52 members; 40 members returned their ballots, of whom 39 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

D. E. PARSONS,
Chairman.

J. W. WHITTEMORE,
Secretary.

EDITORIAL NOTE

Subsequent to the annual meeting Committee C-15 presented to the Society through Committee E-10 on Standards the following recommendations:

Proposed Revision of Tentative Specifications for Sewer Brick (Made from Clay or Shale) (C 32 – 39 T),

Proposed Revision of Tentative Specifications for Building Brick (Made from Clay or Shale) (C 62 – 39 T), and

Proposed Tentative Revision of Standard Methods of Testing Brick (C 67 – 39) in the form of new Tentative Method of Freezing-and-Thawing Test of Brick (C 67 – 39 T), to be added when adopted to the present standard.

These recommendations were accepted by Committee E-10 on August 24, 1939, and the revised tentative specifications and tentative revision appear in the 1939 Book of A.S.T.M. Standards, Part II.

REPORT OF COMMITTEE D-1

ON

PAINT, VARNISH, LACQUER, AND RELATED PRODUCTS

Committee D-1 on Paint, Varnish, Lacquer, and Related Products held two meetings during the year: on June 30, 1938, in Atlantic City, N. J., during the annual meeting of the Society, and on April 3, 1939, in Baltimore, Md., during the meeting of the American Chemical Society.

The committee recommends that the Society continue as a member-body in the Inter-Society Color Council, with M. Rea Paul, an official delegate of the Society, representing the committee.

Committee D-1 has, during the past year, arranged for the presentation of two papers at its meetings as follows:

"Development of a Method of Classifying Paints According to Gloss,"[1] by R. S. Hunter and D. B. Judd, describing work of Group 1, Subcommittee XVIII, and

"Color Retention of House Paints," by C. H. Rose, describing work of Group 1, Subcommittee VII.

During the past year Subcommittee VI on Definitions, which for some time had been discontinued, was reorganized under the chairmanship of C. H. Rose. A special committee was formed, under the chairmanship of G. G. Sward, to develop a Symposium on Testing for this annual meeting of the Society.

Since the last annual meeting, 23 new members have been elected, 10 resignations have been accepted, and 4 deaths reported, leaving a total membership of 224.

Of the three advisers and fourteen D-1 subcommittees, five furnished reports of progress and six submitted detailed reports affecting standards, which have resulted in the committee making the recommendations given below to be acted upon at the annual meeting.

In this report, recommendations affecting standards and tentative standards are noted in brief form below, together with the results of the letter ballot. These recommendations are explained in the reports of the subcommittees directly responsible for them.

I. NEW TENTATIVE STANDARDS

The committee submits for publication as tentative the following two new specifications and three methods of test:[2]

Tentative Specifications for:

Shellac Varnishes, to replace the Standard Specifications for Shellac Varnish (D 359 - 35), and for Centrifuged Shellac Varnish (D 360 - 34), proposed by Subcommittee XIII,

Zinc Dust (Metallic Zinc Powder), proposed by Subcommittee XV,

Tentative Methods of:

Chemical Analysis of Zinc Dust (Metallic Zinc Powder), proposed by Subcommittee VIII,

Test for Specular Gloss of Paint Finishes, proposed by Subcommittee XVIII, and

Test for Elongation of Attached Lacquer Coatings with the Conical Mandrel Test Apparatus, proposed by Subcommittee XXV.

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[1] ASTM BULLETIN, No. 97, March, 1939, p. 11.

[2] These specifications and methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

II. REVISIONS OF STANDARDS

The committee recommends for immediate adoption, revisions in the following standards, and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society:

Standard Specifications for:

Zinc Oxide (D 79 – 24; A.S.A. K22–1937), proposed by Subcommittee XV,
Prussian Blue (D 261 – 28; A.S.A. K29–1937), proposed by Subcommittee XV,
Normal Amyl Acetate (D 318 – 36), proposed by Subcommittee XXV,

Standard Methods of:

Sampling and Testing Shellac (D 29 – 33), proposed by Subcommittee XIII, and
Test for Specific Gravity of Pigments (D 153 – 37; A.S.A. K41–1937), proposed by Subcommittee VIII,
Routine Analysis of White Pigments (D 34 – 33; A.S.A. K15–1933), revised by addition of Standard Methods of Routine Analysis of Titanium Pigments (D 186 – 37; A.S.A. K43–1937) and revision of Methods D 186 proposed by Subcommittee VIII.

The committee further recommends that the revisions proposed in the following standards be accepted for publication as tentative:

Standard Specifications for:

Orange Shellac (D 237 – 33), proposed by Subcommittee XIII,
Butanol (Normal Butyl Alcohol) (D 304 – 33), proposed by Subcommittee XXV,
Amyl Alcohol (Synthetic) (D 319 – 33), proposed by Subcommittee XXV,

Standard Methods of:

Routine Analysis of White Linseed Oil Paints (D 215 – 37), proposed by Subcommittee VIII, and
Sampling and Testing Lacquer Solvents and Diluents (D 268 – 33), proposed by Subcommittee XXV.

III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative standards be approved for reference to letter ballot of the Society for adoption as standard, and that those so indicated be revised as referred to in the reports of the subcommittees:

Tentative Specifications for:

Petroleum Spirits (Mineral Spirits) (D 235 – 34 T), proposed by Subcommittee XI, with an editorial change recommended for purposes of clarification, and to be consistent in terminology, changing the words "dry point" wherever they appear to read "end point,"
Aluminum Pigment Paste for Paint (D 474 – 38 T), proposed by Subcommittee XV,
C.P. Para Red Toner (D 475 – 38 T), proposed by Subcommittee XV,
Zinc Sulfide Pigments (D 477 – 38 T), proposed by Subcommittee XV,
C.P. Zinc Yellow (Zinc Chromate) (D 478 – 38 T), proposed by Subcommittee XV,
Titanium Dioxide Pigments (D 476 – 38 T), revised as proposed by Subcommittee XV,

Tentative Methods of:

Routine Analysis of Zinc Yellow Pigment (Zinc Chromate Yellow) (D 444 – 38 T), revised as proposed by Subcommittee VIII,
Test for Relative Dry Hiding Power of Paints (D 344 – 37 T), revised as proposed by Subcommittee VIII,
Test for Relative Dry Hiding Power of White Pigments (D 406 – 37 T), revised as proposed by Subcommittee VIII,
Analysis for Spectral Apparent Reflectivity of Paints (D 307 – 37 T), revised as proposed by Subcommittee XVIII, and
Test for Soluble Nitrocellulose Base Solutions (D 365 – 35 T), proposed by Subcommittee XXV.

IV. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

The committee recommends that the revisions of the following five standards (in four of which the revisions are in the form of tentative standards) be approved without change for reference to letter ballot of the Society for adoption as standard:

Standard Specifications for:

Red Lead (D 83 – 31; A.S.A. K24–1937), proposed by Subcommittee XV,

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Shellac Varnishes, to replace Standard Specs. D 359 and D 360	50	1	54
Spec. for Zinc Dust (Metallic Zinc Powder)	66	0	39
Chemical Analysis of Zinc Dust (Metallic Zinc Powder)	63	0	42
Test for Specular Gloss of Paint Finishes	69	1	35
Test for Elongation of Attached Lacquer Coatings with the Conical Mandrel Test Apparatus	60	1	44
II. REVISIONS OF STANDARDS			
Spec. for Zinc Oxide (D 79 – 24; A.S.A. K22-1937), immediate adoption	75	0	30
Spec. for Prussian Blue (D 261 – 28; A.S.A. K29-1937), immediate adoption	69	1	35
Spec. for Normal Amyl Acetate (D 318 – 36), immediate adoption	52	0	53
Sampling and Testing Shellac (D 29 – 33), immediate adoption	47	0	58
Test for Specific Gravity of Pigments (D 153 – 27; A.S.A. K41-1937), immediate adoption	87	0	35
Routine Analysis of Titanium Pigments (D 186 – 37; A.S.A K43-1937), immediate adoption	90	0	32
Routine Analysis of White Pigments (D 34 – 33; A.S.A. K15-1933), immediate adoption	73	0	32
Spec. for Orange Shellac (D 237 – 33)	46	1	58
Spec. for Butanol (Normal Butyl Alcohol) (D 304 – 33)	53	0	52
Spec. for Amyl Alcohol (Synthetic) (D 319 – 33)	54	0	51
Routine Analysis of White Linseed Oil Paints (D 215 – 37)	71	2	32
Sampling and Testing Lacquer Solvents and Diluents (D 268 – 33)	49	0	56
III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for Petroleum Spirits (Mineral Spirits) (D 235 – 34 T)	58	4	43
Spec. for Aluminum Pigment Paste for Paint (D 474 – 38 T)	57	1	47
Spec. for C.P. Para Red Toner (D 475 – 38 T)	56	0	49
Spec. for Zinc Sulfide Pigments (D 477 – 38 T)	63	0	42
Spec. for C.P. Zinc Yellow (Zinc Chromate) (D 478 – 38 T)	63	0	42
Spec. for Titanium Dioxide Pigments (D 476 – 38 T), as revised	70	0	35
Routine Analysis of Zinc Yellow Pigment (Zinc Chromate Yellow) (D 444 – 38 T), as revised	61	0	44
Test for Relative Dry Hiding Power of Paints (D 344 – 37 T), as revised	90	0	32
Test for Relative Dry Hiding Power of White Pigments (D 406 – 37 T), as revised	97	1	24
Analysis for Spectral Apparent Reflectivity of Paints (D 307 – 37 T), as revised	64	0	41
Test for Soluble Nitrocellulose Base Solutions (D 365 – 35 T)	40	0	65
IV. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Spec. for Red Lead (D 83 – 31; A.S.A. K24-1937)	60	0	45
Spec. for Commercial Para Red (D 264 – 28; A.S.A. K31-1937)	58	0	47
Spec. for Aluminum Powder for Paints (Aluminum Bronze Powder) (D 266 – 31)	62	0	43
Sampling and Testing Shellac (D 29 – 33)	47	0	58
Routine Analysis of Dry Cuprous Oxide (D 283 – 36)	49	2	54
V. WITHDRAWAL OF STANDARDS AND TENTATIVE STANDARDS			
Spec. for Shellac Varnish (D 359 – 35)	52	0	53
Spec. for Centrifuged Shellac Varnish (D 360 – 34)	51	0	54
Spec. for Lithopone (D 208 – 26)	63	0	42
Spec. for Titanium Barium Pigment (D 382 – 35; A.S.A. K38-1937)	68	0	37
Spec. for Titanium Calcium Pigment (D 383 – 35; A.S.A. K39-1937)	68	0	37
Spec. for Titanium Dioxide (D 384 – 36; A.S.A. K40-1937)	67	0	38
Spec. for Zinc Sulfide - Barium Pigment (D 385 – 36)	64	0	41
Spec. for Zinc Sulfide (D 386 – 36)	65	0	40
Spec. for Titanium Magnesium Pigment (D 442 – 37 T)	68	0	37
Spec. for Zinc Sulfide Magnesium Pigment (D 443 – 37 T)	66	0	39

Commercial Para Red (D 264 – 28; A.S.A. K31–1937) proposed by Subcommittee XV,

Aluminum Powder for Paints (Aluminum Bronze Powder) (D 266 – 31), proposed by Subcommittee XV,

Standard Methods of:

Sampling and Testing Shellac (D 29 – 33), proposed by Subcommittee XIII, and

Routine Analysis of Dry Cuprous Oxide (D 283 – 36), proposed by Subcommittee VIII.

V. WITHDRAWAL OF STANDARDS AND TENTATIVE STANDARDS

The committee recommends the withdrawal of the following standards and tentative standards for the reasons referred to in the reports of the subcommittees:

Standard Specifications for:

- Shellac Varnish (D 359 – 35) proposed by Subcommittee XIII,
- Centrifuged Shellac Varnish (D 360 – 34), proposed by Subcommittee XIII,
- Lithopone (D 208 – 26), proposed by Subcommittee XV,
- Titanium Barium Pigment (D 382 – 35; A.S.A. K38–1937), proposed by Subcommittee XV,
- Titanium Calcium Pigment (D 383 – 35; A.S.A. K39–1937), proposed by Subcommittee XV,
- Titanium Dioxide (D 384 – 36; A.S.A. K40–1937), proposed by Subcommittee XV,
- Zinc Sulfide-Barium Pigment (D 385 – 36), proposed by Subcommittee XV,
- Zinc Sulfide (D 386 – 36), proposed by Subcommittee XV,

Tentative Specifications for:

- Titanium Magnesium Pigment (D 442 – 37 T), proposed by Subcommittee XV, and
- Zinc Sulfide Magnesium Pigment (D 443 – 37 T).

The above recommendations have been submitted to letter ballot of the committee which consists of 187 members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Linseed Oil (R. D. Bonney, adviser).—It is recommended that the present Standard Specifications for Raw Linseed Oil (D 234 – 28), and for Boiled Linseed Oil (D 260 – 33) be retained without revision, since a recent review indicates that satisfactory linseed oil can be produced and obtained meeting these specifications.

Subcommittee VII on Accelerated Tests for Protective Coatings (H. A. Nelson, chairman).—This subcommittee reports progress in the work of its several subgroups. These are engaged in cooperative activities to determine the effectiveness of different accelerated weathering units and certain physical tests in evaluating by accelerated means film performance under normal conditions of exposure or use. Color retention of house paints and tests on enamel coatings are now in progress. The subcommittee recommends the formation of a group to develop a standard procedure for preparing test panels, which group can maintain contact in its testing work with the activities of Subcommittee XXIX on Painting of Structural Iron and Steel.

The appointment of a committee is also recommended to work on the preparation of a pictorial scale for evaluating rust resistance, the proposed committee to consist of representatives of all groups within the Society interested in this subject.

Subcommittee VII plans to arrange for the publication of a questionnaire for the purpose of securing information with respect to tests now in use in evaluating finishes in different laboratories throughout the country.

Subcommittee VIII on Methods of Analysis of Paint Materials (E. F. Hickson, chairman).—This subcommitee recommends for publication as tentative new Methods of Chemical Analysis of Zinc Dust (Metallic Zinc Powder).[3]

Recommendation is also made for the adoption as standard of the present tentative revision[4] of the Standard Method of Routine Analysis of Dry Cuprous Oxide (D 283 – 36).[5] The revision is in the form of Tentative Method D 283 – 38 T and is to replace the present standard.

Adoption as standard is recommended of the Tentative Methods of Routine Analysis of Zinc Yellow Pigment (Zinc Chromate Yellow) (D 444 – 38 T),[6] with the following revision:

Section 7 (b), Procedure.—Change from its present form: namely,

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[3] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 845 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 735.

[5] 1936 Book of A.S.T.M. Standards, Part II, p. 624.

[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 839 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 729.

(*b*) *Procedure.*—To a 400-ml. beaker containing 200 ml. of water, add 2 g. of potassium iodide (solid) and 5 ml. of H_2SO_4 (sp. gr. 1.42). (Final acidity should be approximately 5 ml. of acid per 100 ml. of solution.) Pipette 25 ml. of the chromic acid solution into the solution of KI and H_2SO_4 and after 5 min. titrate with the 0.1 *N* standard sodium thiosulfate solution, using starch as an internal indicator. The percentage of chromic acid may be calculated from the following values:

1 ml. of *N* sodium thiosulfate = 0.01733 g. of Cr. or 0.03334 g. of CrO_3.

Report the amount calculated as percentage of CrO_3.

to read as follows:

(*b*) *Procedure.*—To a 400-ml. beaker containing 200 ml. of water, add 2 g. of potassium iodide (solid) and 5 ml. of H_2SO_4 (sp. gr. 1.84). (Final acidity should be approximately 5 ml. of acid per 100 ml. of solution.) Pipette a 25-ml. aliquot from the zinc chromate - sulfuric acid solution as made up in the zinc oxide determination into a 500-ml. glass-stoppered Erlenmeyer iodimetric flask or other suitable glass-stoppered bottle, containing 200 ml. of diluted sulfuric acid (25 ml. per liter). Add 2 g. of potassium iodide dissolved in 20 ml. of water, stopper, and allow the solution to stand for approximately 5 min. Titrate the liberated iodine with sodium thiosulfate at room temperature until the reddish-brown iodine color becomes quite faint. Then add 5 ml. of freshly prepared starch solution and continue the titration until the final color change becomes pale green with no blue tinge. This final titration should be carried out by twirling the flask at least three times after each addition of the sodium thiosulfate, being sure that there is no further color change, especially at the final stage of the titration. The green end point is definite and sharp. The percentage of chromic acid may be calculated from the following values:

1 ml. of *N* sodiumthiosulfate = 0.03334 g. of CrO_3.

Report the amount calculated as percentage of CrO_3.

Adoption as standard is recommended of the Tentative Method of Test for Relative Dry Hiding Power of Paints (D 344 - 37 T),[7] with a minor revision in the second and third sentences of Section 3, changing "diffuse reflection" to read "diffuse reflectance."

Adoption as standard is recommended of the Tentative Method of Test for Relative Dry Hiding Power of White Pigments (D 406 - 37 T),[7] with a revision in the title and first sentence of Section 1, adding the words "in a linseed oil vehicle" after the word "pigment"; and also in the second and third sentences of Section 3 changing "diffuse reflection" to read "diffuse reflectance."

The subcommittee recommends for immediate adoption in the Standard Methods of Test for Specific Gravity of Pigments (D 153 - 27)[8] a revision in the weight of the glass flask prescribed in the second sentence of Section 13 (*b*) changing "less than 35 g." to read "between 50 and 60 g." This change makes provision for a slightly thicker walled flask.

The subcommittee recommends that the Standard Methods of Routine Analysis of Titanium Pigments (D 186 - 37; A.S.A. K43—1937)[9] be added to the Standard Methods of Routine Analysis of White Pigments (D 34 - 33; A.S.A. K15—1933),[8] this consolidation to become effective immediately. The following revisions for immediate adoption are recommended for inclusion in Methods D 186 before the latter are incorporated in Methods D 34:

Section 9.—Second paragraph, change to read as follows by the addition of the italicized material and the omission of that in brackets:

> Dilute the filtrate to 200 cc. and add about *5 ml.* [10 cc.] of NH_4OH (sp. gr. 0.90) to lower the acidity to approximately *10 to 15* [5] per cent H_2SO_4 (by volume).

Section 9.—Change items (*1*) and (*2*) to read as follows by the addition of the italicized material and the omission of that in brackets:

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[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, pp. 866, 844 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 754, 720.

[8] 1936 Book of A.S.T.M. Standards, Part II, pp. 638, 685, 662.

[9] 1937 Supplement to Book of A.S.T.M. Standards, p. 115.

(*1*) Run 50 cc. of the 5 per cent H_2SO_4 solution through the reductor *at such a uniform rate as to require 5 to 10 min. for passage* [at a speed of about 100 cc. per minute].

(*2*) Follow this with the titanium solution *at such a uniform rate as to require 10 min. to pass through the reductor.*

The above changes are proposed in order to make the methods more reliable for the inexperienced operator.

A tentative revision is recommended in the Standard Methods of Routine Analysis of White Linseed Oil Paints (D 215 – 37)[8], as follows:

Section 31.—Omit the last sentence of the sixth paragraph of the section on calculations which reads as follows: "The procedure followed by the Federal Specifications Board should be noted." Also omit the footnote accompanying this sentence.

This subcommittee reports the completion of cooperative tests for measuring the consistency of five enamel paints, and plans to prepare a tentative method of test for consistency, using the Krebs modified Stormer viscosimeter.

Subcommittee IX on Varnish (W. T. Pearce, chairman).—This subcommittee is studying tests with a plan of defining and measuring the stages of drying that are considered most important to the coatings industry. Methods for measuring resistance to gas-checking are now under consideration, and new groups are being formed by the subcommittee to study methods of chemical analysis and physical tests for driers, chemical resistance tests for furniture and floor varnishes, chemical analysis and tests for alkyd liquids.

Subcommittee XI on Paint Thinners Other Than Turpentine (M. B. Chittick, chairman).—This subcommittee recommends the adoption as standard, without revision, of the Tentative Specifications for Petroleum Spirits (Mineral Spirits) (D 235 – 34 T).[10]

Subcommittee XIII on Shellac (W. H. Gardner, chairman).—This subcommittee is recommending for publication as tentative, new Specifications for Shellac Varnishes,[11] to replace the present Standard Specifications for Shellac Varnish (D 359 – 35),[12] and for Centrifuged Shellac Varnish (D 360 – 34)[12] which are recommended to be withdrawn. The subcommittee points out that there appears to be little demand for shellac varnish which has not had the dirt and insoluble matter removed by modern methods. The combining of specifications D 359 and D 360 as revised will raise the general standard for shellac varnish without causing any undue hardship to the producer.

This subcommittee recommends for publication as tentative the following revision of the Standard Specifications for Orange Shellac (D 237 – 33)[13]

Section 2.—Change the table of physical and chemical requirements to read as follows by the addition of the italicized words and figures and the omission of the figures in brackets:

	Grade A	Grade B	Grade C	Grade D
Iodine number, max.	[18.0]	[18.0]	[18.0]	24.3
Matter insoluble in specified hot solvents, max., per cent	[1.75]*1.25*	[2.50]*2.00*	3.00	3.00
Orpiment, max., per cent	*0.025*	*0.025*	*0.20*	*0.20*
Moisture, max., per cent	2.0	2.0	2.0	2.0
Wax, max., per cent	5.5	5.5	5.5	5.5
Matter soluble in water, max., per cent	0.5	0.5	0.5	0.5
Ash, max., per cent	1.0	1.0	1.0	1.0
Color	when specified, the color shall be no darker than that of a sample mutually agreed upon by purchaser and seller.			

Following the table add a note to read as follows:

NOTE.—Grades A, B, and C should show no presence of rosin when tested in accordance with the qualitative tests described in Section

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[10] *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part I, p. 876 (1934); also 1938 Book of A.S.T.M. Tentative Standards, p. 740.

[11] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

[12] 1936 Book of A.S.T.M. Standards, Part II, pp. 755, 757.

[13] 1936 Book of A.S.T.M. Standards, Part II, p. 754.

14 of the Standard Methods of Sampling and Testing Shellac (D 29 – 33).

Subcommittee XIII recommends the adoption of the tentative revision published since 1936 in the Standard Methods of Sampling and Testing Shellac (D 29 – 33),[14] which provides for the deletion of Section 19 describing the procedure for the determination of wax in orange, button, seed, and regular bleached shellac.

The subcommittee recommends for immediate adoption a further revision in Methods D 29, as follows:

Sections 20 and 21.—Omit the center heading of Section 20 which reads, "B. For Machine-made Shellac and Garnet Lac and Optional Method in Place of Method A," renumbering this section as Section 19. Omit Section 21 which describes the procedure for the determination of wax in dry-bleached refined shellac and garnet lacs of low wax content; the subcommittee believes that this method frequently gives difficulty and that equally satisfactory results can be obtained by the procedure described in Section 20 (new Section 19).

New Sections.—Add as new Sections 20 to 22, inclusive, a test for the determination of orpiment in orange shellac,[15] renumbering the subsequent sections accordingly.

Subcommittee XV on Specifications for Pigments Dry and in Oil When Marketed in That Form (H. E. Smith, chairman). In the report of Subcommittee XV, appended hereto, the several recommendations mentioned earlier in this report are discussed in detail.

Subcommittee XVIII on Physical Properties of Materials (M. Rea Paul, chairman).—This subcommittee recommends for publication as tentative, a new Method of Test for Specular Gloss of Paint Finishes.[16] The subcommittee further recommends the adoption as standard of the Tentative Method of Test for Spectral Apparent Reflectivity of Paints (D 307 – 37 T),[17] with the following minor revision:

Section 7 (b).—In the note to this section, change "440 m μ." to read "400 m μ."

Subcommittee XXV on Cellulose Ester Coatings (R. M. Carter, chairman).—This subcommittee recommends for publication as tentative a new Method of Test for Elongation of Attached Lacquer Coatings with the Conical Mandrel Test Apparatus.[16]

A new method of test for toluene (toluol) dilution ratio of lacquer solvents[16] is recommended for publication as a tentative revision of the Standard Methods of Sampling and Testing Lacquer Solvents and Diluents (D 268 – 33).[18] The following editorial changes are presented for inclusion in the methods:

Section 17, Procedure.—In the fifth sentence change the normality of sodium thiosulfate from "0.5 *N* $Na_2S_2O_3$" to read "0.05 *N* $Na_2S_2O_3$."

Section 18.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

> 18. To 100 ml. of acetone contained in a 250-ml. [Erlenmeyer flask] *glass-stoppered container* and maintained at 25 C., 1 ml. of 0.1 per cent potassium permanganate solution shall be added with slight stirring. *The test should be conducted in the dark as sunlight appreciably affects the results.*

A tentative revision is proposed in the Standard Specifications for Butanol

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[14] 1936 Book of A.S.T.M. Standards, Part II, p. 760.

[15] This method of test was adopted as standard by the Society and appears in the Standard Methods of Sampling and Analysis of Shellac (D 29 – 39), 1939 Book of A.S.T.M. Standards, Part II.

[16] This method was accepted as tentative by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part II.

[17] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 869 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 759.

[18] 1936 Book of A.S.T.M. Standards, Part II, pp. 813, 789, 787.

(Normal Butyl Alcohol) (D 304 - 33)[18] as follows:

Section 1.—In the table of physical and chemical requirements omit the requirement reading "Purity . . . to contain not less than 98 per cent of normal butyl alcohol." This is recommended because there is at present no acceptable method of test which is applicable.

Change the requirement for water from "no cloud when one volume of Butanol is mixed with 19 volumes of 60° Baumé gasoline at 20 C." to read "miscible without turbidity with 19 volumes of 60° A.P.I. gasoline at 20 C."

A tentative revision is proposed in the Standard Specifications for Amyl Alcohol (Synthetic) (D 319 - 33),[18] as follows:

Section 1.—In the table of physical and chemical requirements omit the requirement reading, "Purity . . . consists of a mixture of the various isomeric forms of amyl alcohol and contains at least 98 per cent of these alcohols" since, as mentioned above, no acceptable method of test is at present available.

Subcommittee XXV also recommends a revision of the Standard Specifications for Normal Amyl Acetate (D 318 - 36).[19] The proposed revision comprises separating Specifications D 318 into two distinct standards, one to be entitled "Standard Specifications for Synthetic Amyl Acetate," and the other, "Standard Specifications for Amyl Acetate Made from Fusel Oil." This subcommittee further recommends that the word "normal" be deleted wherever it appears in Standard Specifications D 318 since it is incorrect and misleading. In view of the fact that the above revisions do not alter the sense of the specifications, it is recommended that these changes be accepted for immediate adoption.

It is recommended that the Tentative Methods of Test for Soluble Nitrocellulose Base Solutions (D 365 - 35 T)[20] be adopted as standard without revision.

A special subcommittee of Committee D-2 on Petroleum Products and Lubricants has considered the proposal to recommend to the Interstate Commerce Commission the use of a closed-cup tester in place of the open-cup tester in its classification of flammable liquids, and has made the following recommendation:

"Change the lower limit for flammable liquids from 80 to 70 F. with a corresponding change from the open-cup tester to one of two closed-cup testers, as follows:

(*a*) For products with viscosities of 7.4 centistokes at 100 F. (50 sec. Saybolt) or less, use the Tag closed tester described in the Standard Method of Test for Flash Point by Means of the Tag Closed Tester (A.S.T.M. Designation: D 56) of the American Society for Testing Materials.

(*b*) For products with viscosities of over 7.4 centistokes at 100 F., use the Pensky-Martens tester as described in the Standard Method of Test for Flash Point by Means of the Pensky-Martens Closed Tester (A.S.T.M. Designation: D 93) of the American Society for Testing Materials."

This subcommittee desires to go on record as expressing its agreement in principle with the action of Committee D-2 in the matter of flash point determination, but recommends that the decrease in flash point be established by the Interstate Commerce Commission.

Subcommittee XXV recommends the following editorial change in the Standard Specifications for Industrial 90 per cent Benzene (Benzol) (D 361 - 36):[21]

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[19] 1936 Book of A.S.T.M. Standards, Part II, p. 785.

[20] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 889 (1935); also 1938 Book of A.S.T.M. Tentative Standards, p. 748.

[21] 1936 Book of A.S.T.M. Standards, Part II, p. 788.

Section 1.—In the table of physical and chemical requirements change the requirement for water from "not sufficient to show turbidity" to read "not sufficient to show turbidity at 20 C."

This subcommittee further recommends that all other standards and tentative standards under its jurisdiction be continued in their present status.

This report has been submitted to letter ballot of the committee which consists of 224 members; 105 members returned their ballots, of whom 88 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

H. E. SMITH,
Chairman.

M. REA PAUL,
Secretary.

REPORT OF SUBCOMMITTEE XV ON SPECIFICATIONS FOR PIGMENTS DRY AND IN OIL WHEN MARKETED IN THAT FORM

New Tentative Standard:

Subcommittee XV is presenting for publication as tentative new Specifications for Zinc Dust (Metallic Zinc Powder)[1] as it believes that metallic zinc dust pigment is now used to such an extent as a corrosion-resistant coating as to merit its being covered by A.S.T.M. specifications.

Revisions of Standards:

Revisions are recommended for immediate adoption in the present Standard Specifications for Zinc Oxide (D 79 – 24; A.S.A. K22-1937)[2] as indicated below. The changes being made in Section 2 on process are in line with the policy of specifying the material on the basis of the properties and tests of the finished product, rather than the process of manufacture. A revision is being recommended in Section 3 on composition and properties in order to give the purchaser the opportunity to specify the physical properties more or less completely according to the requirements of his intended use of the pigment.

Section 2.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

2. (*a*) Pigment.—The pigment [may be made by] *shall be zinc oxide of either* the American process *type* [direct from the ore,] or [by] the French process *type* [from spelter]. The order or contract shall state which is desired.

(*b*) Paste.—The paste shall be made by thoroughly grinding the specified pigment with [pure raw or refined] linseed oil.

Section 3.—Change Paragraph (*a*) from its present form: namely,

3. (*a*) The color and color strength, when specified, shall be equal to that of a sample mutually agreed upon by buyer and seller.

to read as follows:

3. (*a*) In such physical properties as are specified by the purchaser, the pigment shall satisfactorily match a reference sample mutually agreed upon by the purchaser and the seller.

In Paragraph (*b*) add an additional requirement for moisture to read as follows:

	American Process		French Process	
	Max.	Min.	Max.	Min.
Moisture and other volatile matter, per cent	0.5	..	0.5	..

The subcommittee recommends for immediate adoption revisions as indicated below in the Standard Specifications for Prussian Blue (D 261 – 28; A.S.A. K29-1937).[3] It is pointed out that this pigment is very hygroscopic and the average good and successful commercial material often contains much more than the low limit which was assigned.

Section 3.—In Paragraph (*b*) add the following requirement: "Moisture and other volatile matter, 7.0 per cent, max."

In Paragraph (*c*) change the requirement for moisture and other volatile matter from "0.7 max., per cent" to read "3.0 max., per cent."

Adoption of Tentative Standards as Standard:

The subcommittee is recommending

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[1] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

[2] 1936 Book of A.S.T.M. Standards, Part II, p. 606.

[3] *Ibid.*, p. 588.

the adoption as standard of the following five tentative specifications;[4] with a revision in one of the specifications as given below:

Tentative Specifications for:

Aluminum Pigment Paste for Paint (D 474 - 38 T),
C.P. Para Red Toner (D 475 - 38 T),
Zinc Sulfide Pigments (D 477 - 38 T),
C.P. Zinc Yellow (Zinc Chromate) (D 478 - 38 T), and
Titanium Dioxide Pigments (D 476 - 38 T), revised as follows:

Attention is called to the fact that the requirement for titanium dioxide in titanium-barium pigment is now 24 per cent minimum. A grade carrying 28 per cent is at present the most used commercial product, although small quantities of pigment containing 24 per cent are still made. To meet this condition, the following revision is recommended:

Section 3 (b).—In the table of requirements, under titanium barium pigment, change the minimum requirement for titanium dioxide from "24.0 per cent," to read "Class A, 28.0 per cent" and "Class B, 24.0 per cent."

Adoption as Standard of Tentative Revisions of Standards:

The subcommittee is recommending that the revisions[5] of the following three standard specifications[6] (in the form of tentative standards) be approved for adoption as standard:

Standard Specifications for:

Red Lead (D 83 - 31; A.S.A. K24-1937),
Commercial Para Red (D 264 - 28; A.S.A. K31-1937), and
Aluminum Powder for Paints (Aluminum Bronze Powder) (D 266 - 31).

Withdrawal of Standards and Tentative Standards:

Withdrawal of the following specifications is recommended since they are to be superseded by new or revised specifications:

Standard Specifications[7] for:

Lithopone (D 208 - 26),
Titanium Barium Pigment (D 382 - 35; A.S.A. K38-1937),
Titanium Calcium Pigment (D 383 - 35; A.S.A. K39-1937),
Titanium Dioxide (D 384 - 36; A.S.A. K40-1937),
Zinc Sulfide Pigment (Barium) (D 385 - 36),
Zinc Sulfide (D 386 - 36),

Tentative Specifications[8] for:

Titanium Magnesium Pigment (D 442 - 37 T), and
Zinc Sulfide Magnesium Pigment (D 443 - 37 T).

Editorial Changes:

Certain editorial changes are being recommended for the sake of uniformity and precision in several of the pigment specifications. The expression proposed for designating moisture and volatile matter is that now used in the greater number of pigment specifications. These editorial changes are as follows:

In Section 3 (*c*) of the Standard Specifications for Chrome Yellow (D 211 - 27; A.S.A. K27-1937)[9] change "Water and other volatile matter . . ." to read "Moisture and other volatile matter . . ."

In Section 3 (*c*) of the Standard Specifications for Lampblack (D 209 - 30; A.S.A. K26-1937)[9] change "Material volatile at 105 C." to read "Moisture and other volatile matter, per cent."

In Section 3 (*c*) of the Standard Specifications for Ochre (D 85 - 27)[9] change "Moisture and volatile matter, per cent" to read "Moisture and other volatile matter, per cent."

The subcommittee further recommends that all standards and tentative standards for pigments, except those enumerated below, be revised editorially by the addition of a general clause on methods of test, to read as follows:

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 822, 826, 833, 831, 829 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 703, 707, 716, 714, 710.

[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 827, 824, 821 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 708, 705, 702.

[6] 1936 Book of A.S.T.M. Standards, Part II, pp. 590, 586, 565.

[7] 1936 Book of A.S.T.M. Standards, Part II, pp. 582, 592, 594, 596, 612, 610.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, pp. 840, 842 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 712, 718.

[9] 1936 Book of A.S.T.M. Standards, Part II, pp. 576, 580, 584.

> *Methods of Test.*—Tests shall be conducted in accordance with the appropriate methods of the American Society for Testing Materials, where applicable. Test procedures not covered by A.S.T.M. methods shall be mutually agreed upon by the purchaser and the seller.

Those pigment specifications in which such a section is now included should have that section revised in wording to be consistent with the above recommendation. The two exceptions are the Specifications for Aluminum Powder for Paints (Aluminum Bronze Powder) (D 266), and for Aluminum Pigment Paste for Paint (D 474), since both of these specifications contain a reference to the methods of analyzing aluminum pigments for paste.

The subcommittee has before it for consideration, a revision of the Standard Specifications for Leaded Zinc Oxide (D 80 - 24) to provide requirements for various classes with respect to percentage of lead compounds in order to meet present commercial conditions; a study of the moisture content of nominally dry pigment, with a view to specifying requirements for this impurity where needed; the preparation of specifications for carbon black pigment; and a revision of the Standard Specifications for Ultramarine Blue (D 262 - 28) for the purpose of describing more definitely the normal composition of the pigment.

Respectfully submitted on behalf of the subcommittee,

H. E. SMITH,
Chairman.

REPORT OF COMMITTEE D-2
ON
PETROLEUM PRODUCTS AND LUBRICANTS

Committee D-2 on Petroleum Products and Lubricants held three regular meetings during the past year (in June at Atlantic City, N. J., in January at Detroit, Mich., and in March at Washington, D. C.).

During the year the following changes in subcommittees and technical committees have been made: Subcommittee I on Pharmaceutical Tests has been organized, and Subcommittee X on Sligh Oxidation Test has been discontinued; a new Section VIII on Aviation Gasoline Specifications of Technical Committee A has been organized, and Section III on Vapor Lock has been discontinued.

The following tabulation contains changes in status of American standards and American tentative standards for petroleum products, approved by the American Standards Association on the recommendation of Sectional Committee Z11 on Petroleum Products and Lubricants:

Title	A.S.T.M. Designation	A.S.A. Number
REVISION OF AMERICAN TENTATIVE STANDARD		
Method of Test for Knock Characteristics of Motor Fuels	D 357 - 38 T	Z11.37 - 1938
REVISION OF AMERICAN STANDARDS		
Method of Test for Distillation of Gas Oil and Similar Distillate Fuel Oils	D 158 - 38	Z11.26 - 1938
Method of Test for Viscosity by Means of Saybolt Viscosimeter	D 88 - 38	Z11.2 - 1938
Method of Test for Distillation of Gasoline, Naphtha, Kerosine and Similar Petroleum Products	D 86 - 38	Z11.10 - 1938
ADVANCEMENT OF AMERICAN TENTATIVE STANDARD TO AMERICAN STANDARD		
Method of Test for Color of Refined Petroleum Oil by Means of Saybolt Chromometer	D 156 - 38	Z11.35 - 1938
WITHDRAWAL OF AMERICAN STANDARDS		
Method of Test for Saponification Number	D 94 - 36	Z11.20 - 1936
Method of Test for Penetration of Greases and Petrolatum	D 217 - 33 T	Z11.3 - 1933

The voting membership of Committee D-2 now consists of 36 producers, 31 consumers, and 12 general interest members.

A Symposium on Determination of Sulfur in Petroleum Oils by Lamp Methods was held in connection with the Washington meeting of the committee. The papers dealt with the accuracy and reproducibility of the present A.S.T.M. method and various modifications employed in research laboratories. Subcommittee VII on Sulfur (H. M. Hancock, chairman) plans further work to improve the Tentative Method of Test for Sulfur in Petroleum Oils by Lamp Method (D 90 - 34 T).

Subcommittee XIII on Neutralization Number and Saponification (E. B. McConnell, chairman) has undertaken a program to improve the Tentative Method of Test for Neutralization Number (D 188 - 27 T) as applied to used oils. Meanwhile a revision of the method has been found to yield reproducible results on used aviation oils and is presented as information in an appendix to this report.

Subcommittee XXIII on Carbon Residue (L. C. Beard, Jr., chairman) has made a comparison on six oils by the

TABLE I.—RESULTS OF CARBON RESIDUE TESTS BY A.S.T.M. STANDARD METHOD D 189 (CONRADSON CARBON RESIDUE) AND RAMSBOTTOM METHOD OF THE INSTITUTE OF PETROLEUM (GREAT BRITAIN).

Sample	Saybolt Universal Viscosimeter, sec.	Carbon Residue Method	Laboratory								Average	Deviation from Average, per cent		
			1	2	3	4	5	6	7	8		Maximum	Mean	[a]
Midcontinent Bright Stock	150 at 210 F.	A.S.T.M. D 189[b]	1.68	1.40	1.70	1.70	1.68	1.47	1.55	1.69	1.61	13.0 (14.9)[c]	6.3	
		Ramsbottom[b]	1.20	1.11	1.21	1.18	1.18	1.09	1.19	1.19	1.17	6.8 (12.8)	2.9	0.46
Pale Paraffin Oil	100 at 100 F.	A.S.T.M. D 189	0.031	0.020	0.022	0.023	0.028	0.013	0.017	0.017	0.021	47.6 (66.7)	21.9	
		Ramsbottom	0.120	0.079	0.114	0.099	0.144	0.083	0.107	0.110	0.107	33.8 (49.5)	14.0	0.64
Motor Oil S.A.E. 30	65 at 210 F.	A.S.T.M. D 189	0.28	0.28	0.25	0.24	0.31	0.27	0.24	0.32	0.27	18.5 (22.2)	8.8	
		Ramsbottom	0.29	0.21	0.26	0.24	0.27	0.23	0.27	0.27	0.26	19.2 (26.9)	7.7	0.88
Coastal Bright Stock	150 at 210 F.	A.S.T.M. D 189	1.39	1.41	1.37	1.39	1.31	1.21	1.12	1.32	1.32	15.1 (17.4)	5.7	
		Ramsbottom	0.86	0.76	0.94	0.90	0.87	0.79	0.86	0.89	0.86	11.6 (16.3)	4.8	0.84
No. 6 Fuel Oil	....	A.S.T.M. D 189	13.4	13.9	13.4	13.6	14.1	14.4	14.1	13.6	13.8	4.3 (6.5)	2.3	
		Ramsbottom	11.3	11.3	11.2	11.2	11.1	10.7	11.5	11.4	11.2	4.6 (6.2)	1.4	0.61
10 Per Cent Residuum from Kerosine	....	A.S.T.M. D 189	0.035	0.030	0.012	0.016	0.050	0.019	0.016	0.020	0.025	100.0 (156.0)	41.0	
		Ramsbottom	0.089	0.041	0.072	0.050	0.120	0.060	0.075	0.094	0.075	60.0 (78.7)	25.8	0.63
												Average		0.68

[a] Values in this column are the mean deviation Ramsbottom carbon residues divided by mean deviation A.S.T.M. carbon residues.

[b] The values from each laboratory are the average of 2, 3, or 4 determinations, usually 3.

[c] The values in parentheses represent the maximum deviation of any individual determination reported to the subcommittee. These individual results are not included in the tabulation, only laboratory averages.

Standard Method of Test for Carbon Residue of Petroleum Products (Conradson Carbon Residue) (D 189 – 36) and the Ramsbottom Method of The Institute of Petroleum of Great Britain. The results are contained in Table I. Better reproducibility was obtained with the Ramsbottom method, and this test is accordingly being recommended for publication as tentative.

Section I on Gum (T. H. Rogers, chairman) of Technical Committee A on Gasoline has developed a method for gum stability that is being recommended for publication as tentative as indicated below. The report of the section is appended hereto.

Section VII on Tetraethyl Lead in Gasoline (Graham Edgar, chairman) of Technical Committee A has studied methods for determining tetraethyl lead in gasoline and the HCl reflux method is being recommended for publication as tentative. The report of the section is appended hereto.

Section VIII on Aviation Gasoline Specifications (J. B. Macauley, Jr., Chairman) of Technical Committee A on Gasoline, composed of representatives of the Army, Navy, producers of aviation gasoline, aircraft engine manufacturers and air transport operators, has recommended the publication as information only of specifications for aviation gasolines.[1]

I. NEW TENTATIVE STANDARDS

The committee recommends that the following three methods of test be accepted for publication as tentative:[2]

Tentative Methods of:

Test for Carbon Residue of Petroleum Products (Ramsbottom Carbon Residue), proposed by Subcommittee XXIII on Carbon Residue (L. C. Beard, Jr., chairman),

Test for Gum Stability of Gasoline, proposed by Technical Committee A on Gasoline (C. B. Veal, chairman), and

Test for Tetraethyl Lead in Gasoline, proposed by Technical Committee A.

II. REVISIONS OF TENTATIVE STANDARDS

The committee recommends revisions of six tentative standards, as follows:

Tentative Methods of Test for Color of Lubricating Oils by Means of A.S.T.M. Union Colorimeter (D 155 – 34 T),[3] and Test for Color of Petrolatum by Means of A.S.T.M. Union Colorimeter (D 218 – 34 T):[3]

The committee recommends that these two methods be combined into a single method[4] by making the necessary editorial additions to Method D 155.

Tentative Method of Test for Distillation of Plant Spray Oils (D 447 – 37 T):[5]

The following addition is recommended by Subcommittee XVII on Plant Spray Oils (J. B. Terry, chairman) to provide the usual correction for barometric pressure:

Section 6.—Add a new Section 6 to read as follows:

> 6.—The actual barometric pressure shall be ascertained and recorded, but no correction shall be made except in case of dispute. In such cases the temperature points shall be corrected to 760 mm. (29.92 in.) by the use of the Sydney Young equation, as follows:
>
> For Centigrade readings:
>
> $$C_c = 0.00012\ (760 - P)\ (273 + t_c)$$
>
> For Fahrenheit readings:
>
> $$C_f = 0.00012\ (760 - P)\ (460 + t_f)$$
>
> where:
>
> C_c and C_f = correction to be added to the observed temperature t_c or t_f respectively, and
>
> P = actual barometric pressure in millimeters of mercury.

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[1] See p. 414.

[2] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part I, pp. 885, 890 (1934); also 1938 Book of A.S.T.M. Tentative Standards, pp. 775, 779.

[4] This method was accepted as tentative by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part III.

[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 875 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 788.

Tentative Methods of Test for Saponification Number (D 94 – 38 T):[6]

The following revision is recommended by Subcommittee XIII on Neutralization Number and Saponification (E. B. McConnell, chairman):

Section 1.—Change the first sentence of the description of Method B to read as follows by addition of the italicized words and omission of the word in brackets:

> Method B, used for the determination of the saponification number of new and used electrical insulating oils, and other new and used noncompounded [petroleum] oils, *except that Method A shall be used on oils found to have a saponification number of 5.0 or greater by this method.*

Sections 11 and 12.—In the sixth and fifth sentences, respectively, of these sections change the time of refluxing from "30 min." to read "2 hr."

Tentative Method of Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323 – 38 T):[7]

The following minor improvements in this method are recommended by Subcommittee XXII on Natural Gasoline (G. G. Oberfell, chairman):

Section 2 (a).—After the second sentence add a new sentence as follows:

> The internal diameter of the connection between the air chamber and the pressure gage shall be not less than $\frac{3}{16}$ in.

Section 3.—Change the first sentence to read as follows by the addition of the italicized words:

> The pressure gage shall be a Bourdon-type spring gage of test-gage quality, $4\frac{1}{2}$ to $5\frac{1}{2}$ in. in diameter *with a passageway not less than $\frac{3}{16}$ in. in diameter from the Bourdon tube to the atmosphere.*

Section 16 (c).—Change this paragraph to read as follows by the addition of the italicized words:

> (*c*) The air chamber shall be thoroughly purged of liquid gasoline and gasoline vapor. *This may be accomplished* by filling the air chamber with warm water (above 90 F.) and allowing it to drain, repeating the operation at least five times (Note 5).

Tentative Methods of Test for Kinematic Viscosity (D 445 – 38 T):[8]

The following revision is recommended by Subcommittee V on Viscosity (J. C. Geniesse, chairman) in order to permit the use of additional forms of capillary-tube viscosimeters that will give equal accuracy:

Substitute the following general statements for the present statement on Scope and follow with the present Methods A and B as appendices:

> 1. *Scope.*—This method is intended for determining the kinematic viscosity of any petroleum product or lubricant which is a true viscous liquid at the temperature of the test.
>
> 2. *Apparatus.*—The apparatus shall be of the capillary type and shall be capable, under proper manipulation, of measuring viscosity with an error not greater than 0.2 per cent within the viscosity range in which it is to be used.
>
> 3. (*a*) *Procedure.*—Two procedures meeting the requirements prescribed in Section 2 appear in the Appendix.
>
> (*b*) No method shall be used unless it gives an accuracy equal to or greater than (not more than 0.2 per cent error) the methods referred to in Paragraph (*a*), when testing the standards given in Section 4 (*a*) and (*b*).
>
> 4. (*a*) *Calibration.*—Pure distilled water shall be the primary viscosity standard. The kinematic viscosity of water shall be taken as:
>
> 1.007 centistokes at 68 F. (20 C.)
> 0.689 centistokes at 100 F. (37.8 C.)
> 0.518 centistokes at 130 F. (54.4 C.)
>
> Note.—For calibration of viscosimeters by means of water, see Section . . .[a].
>
> [a] Section 5 (*b*) in Method D 445 - 38 T.[8]

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[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 881 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 809.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 890 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 822.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 900 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 832.

(*b*) Oil samples may be used as secondary standards. These oil standards may be obtained from the American Petroleum Institute or the National Bureau of Standards. Also oil samples whose viscosities have been determined by a procedure conforming to the requirements prescribed in Section 2 may be used as secondary standards.

III. REVISIONS OF STANDARDS

The committee recommends for immediate adoption, revisions in five standard methods of test, as indicated below, and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to Society letter ballot:

Standard Method of Test for Burning Quality of Kerosine Oils (D 187 – 36):[9]

The following amplification of the information to be reported at the end of a burning test is recommended by Subcommittee XIX on Illuminating Oils (L. C. Beard, Jr., chairman):

Section 4(d).—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

> At the end of the test, the height and width of the flame and [the condition of the chimney, flame, and wick,] *any change in these dimensions during the performance of the test* shall be [observed and] recorded. The final flame measurement shall be taken without refilling the lamp. *The chimney shall be examined and any deposit on it shall be reported as light, medium, or heavy. The color of the deposit shall be described, for example, as white, yellow, or brown. The tensile strength of the wick fiber as determined by pulling the charred portion with the fingers shall be qualitatively expressed by designating the wick fiber as uninjured, weakened, or destroyed.*

Standard Method of Test for Cloud and Pour Points (D 97 – 34):[10]

The revision given below in the specification for the A.S.T.M. low cloud and pour-point thermometer is recommended by Subcommittee XVI on Cloud and Pour Test (L. C. Beard, Jr., chairman). In explanation of these changes, the subcommittee states that both cloud- and pour-point thermometers are calibrated for 4¼-in. immersion and are employed at approximately that immersion in making the cloud test. In making the pour test, the thermometer is raised so that the immersion is about 3 in., which causes an error of about 5 F. at −30 F. in the low thermometer. The change in immersion of this thermometer increases its accuracy for use in determining pour points while sacrificing accuracy in determining cloud point, and is proposed because of the greater importance of the former. No change is recommended for the mercury thermometer used above −30 F. because of the small error resulting in variation of immersion of this type of thermometer.

Section 3(b), Table II.—Change the paragraph on immersion and standardization to read as follows by the addition of the italicized words and figures and the omission of those in brackets:

> IMMERSION: [108 mm. (4¼ in.)] *76 mm.* (*3 in.*). The words "[108] *76*-mm. immersion" on Centigrade thermometers, or "[4¼] *3*-in. immersion" on Fahrenheit thermometers, and a line around the stem [108 mm. (4.25 in.)] *76 mm.* (*3 in.*) above the bottom of the bulb, shall be etched on the thermometer.
>
> STANDARDIZATION: The thermometer shall be standardized at the ice point and at intervals of approximately 20 C. or 35 F. for [108] *76*-mm. or [4¼] *3*-in. immersion, and for an average temperature of 21 C. or 70 F. for the emergent liquid column.

Standard Method of Test for Distillation of Natural Gasoline (D 216 – 32):[11]

The following addition is recommended by Subcommittee XXII on

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[9] Compilation of "A.S.T.M. Standards on Petroleum Products and Lubricants," p. 29, October, 1938, available as a separate publication. Originally published, prior to editorial rearrangement, in 1936 Book of A.S.T.M. Standards, Part II, p. 834.

[10] Compilation of "A.S.T.M. Standards on Petroleum Products and Lubricants," p. 42, October, 1938, available as a separate publication. Originally published, prior to editorial rearrangement, in 1936 Book of A.S.T.M. Standards, Part II, p. 853.

[11] Compilation of "A.S.T.M. Standards on Petroleum Products and Lubricants," p. 82, October, 1938, available as a separate publication. Originally published, prior to editorial rearrangement, in 1936 Book of A.S.T.M. Standards, Part II, p. 879.

Natural Gasoline (G. G. Oberfell, chairman):

Section 5.—Add the following as a new Paragraph *(g)*:

> *(g)* The sum of the volume collected in the cylinder at any specified temperature and the distillation loss may be recorded as the percentage evaporated at the temperature in question.

Standard Method of Test for Sulfur in Petroleum Oils by Bomb Method (D 129 - 34):[12]

A revision of this method,[13] involving a rearrangement and numerous changes of an editorial nature in the text, is recommended by Subcommittee VII on Sulfur Determination (H. M. Hancock, chairman).

Standard Method of Test for Thermal Value of Fuel Oil (D 240 - 27):[14]

A revision of this method,[15] involving changes primarily of an editorial nature, is recommended by a special subcommittee.

IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following five tentative standards be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Method of Test for Acid Heat of Gasoline (D 481 - 38 T),[16] on the recommendation of Technical Committee A on Gasoline (C. B. Veal, chairman), revised to clarify the wording about the fit of the cork, as follows:

Section 2(b).—Change the second sentence to read as follows, by the addition of the italicized words and the omission of those in brackets:

> This rubber stopper shall [fit snugly in the mouth of the bottle] ***be shaped to seat on the rim of this bottle, the inserted portion fitting loosely in the neck***, and means shall be provided to hold the rubber stopper firmly in place.

Tentative Method of Test for Knock Characteristics of Motor Fuels (D 357 - 38 T),[17] on the recommendation of Technical Committee A, revised as follows:

Section 1.—Delete the word "the" before "knock" in the first sentence; add an explanatory note to the section on Scope, to read as follows:

> NOTE.—The field of knock testing is complex and the following statement of fact, while well-known to the expert, is presented as a warning to others who might assume that the test may be used without limitations to evaluate motor fuels in service:
>
> It has been demonstrated through years of research that no single laboratory test can be used as an accurate measure of the knock characteristics of a motor fuel. The tendency of a fuel to knock varies in different engines and depends upon the weather conditions, the adjustment of the spark, carburetor, etc., and the design and condition of the engine. When used in a given engine, the complete knock characteristics of a given motor fuel can be determined only by running the fuel in that engine under varying driving conditions. The A.S.T.M. octane number is an evaluation of the knock characteristics of the fuel in the C.F.R. engine under arbitrarily prescribed test conditions. Deviations of ratings of fuels on the road from ratings by the A.S.T.M. method may be large. In general these deviations are less than ±3 octane numbers, although in exceptional cases they may amount to as much as 10 octane numbers.

Tentative Viscosity-Temperature Charts for Liquid Petroleum Products (D 341 - 37 T)[18] *and Method for Conversion of Kinematic Viscosity to Saybolt Universal*

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[12] 1936 Book of A.S.T.M. Standards, Part II, p. 974.

[13] This method was adopted as standard by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part III.

[14] 1936 Book of A.S.T.M. Standards, Part II, p. 977.

[15] This method was adopted as standard by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part III.

[16] Compilation of "A.S.T.M. Standards on Petroleum Products and Lubricants," p. 16, October, 1938, available as a separate publication. Originally published in *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 862 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 771.

[17] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 871 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 791.

[18] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, pp. 914, 911 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 841, 845.

sal Viscosity (*D 446 — 37 T*),[18] on the recommendation of Subcommittee V on Viscosity (J. C. Geniesse, chairman).

Tentative Definitions of Terms Relating to Petroleum (*D 288 — 36 T*),[19] on the recommendation of Subcommittee XX on Nomenclature (A. E. Miller, chairman).

TABLE II.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
PUBLICATION AS INFORMATION ONLY			
Spec. for Aviation Gasoline	36	1	13
I. NEW TENTATIVE STANDARDS			
Test for Carbon Residue of Petroleum Products (Ramsbottom Carbon Residue)	47	0	3
Test for Gum Stability of Gasoline	43	0	7
Test for Tetraethyl Lead in Gasoline	43	0	10
II. REVISIONS OF TENTATIVE STANDARDS			
Test for Color of Lubricating Oils (D 155 – 34 T), and Color of Petrolatum (D 218 – 34 T) by A.S.T.M. Union Colorimeter, combined into one method	56	1	7
Tentative Method of Test for Distillation of Plant Spray Oils (D 447 – 37 T)	41	0	9
Test for Saponification Number (D 94 – 38 T)	58	1	5
Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323 – 38 T)	56	0	8
Test for Kinematic Viscosity (D 445 – 38 T)	61	1	2
III. REVISIONS OF STANDARDS			
Test for Burning Quality of Kerosine Oils (D 187 – 36), immediate adoption	44	0	6
Test for Cloud and Pour Points (D 97 – 34), immediate adoption	61	0	3
Test for Distillation of Natural Gasoline (D 216 – 32), immediate adoption	54	0	10
Test for Sulfur in Petroleum Oils by Bomb Method (D 129 – 34), immediate adoption	49	0	1
Test for Thermal Value of Fuel Oil (D 240 – 27), immediate adoption	45	0	5
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test for Acid Heat of Gasoline (D 481 – 38 T), as revised	52	0	12
Test for Knock Characteristics of Motor Fuels (D 357 – 38 T), as revised	49	0	15
Viscosity - Temperature Charts for Liquid Petroleum Products (D 341 – 37 T)	49	0	1
Method for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity (D 446 – 37 T)	49	0	1
Def. of Terms Relating to Petroleum (D 288 – 36 T)	48	0	2
V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Test for Carbon Residue of Petroleum Products (Conradson Carbon Residue) (D 189 – 36)	61	1	2
Test for Cloud and Pour Points (D 97 – 34)	61	0	3
Test for Gravity of Petroleum and Petroleum Products by Means of the Hydrometer (D 287 – 37)	62	0	2
VI. WITHDRAWAL OF TENTATIVE STANDARDS			
Test for Expressible Oil and Moisture in Paraffin Waxes (D 308 – 29 T)	46	0	18

V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

The committee recommends that the tentative revisions published last year[20] of the following three methods be referred to letter ballot of the Society for adoption as standard:

Standard Methods of Test for:

Carbon Residue of Petroleum Products (Conradson Carbon Residue) (D 189 - 36; A.S.A. Z11.25 - 1936),

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[19] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part 1, p. 857 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 847.

[20] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1331 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1697.

Cloud and Pour Points (D 97 - 34; A.S.A. Z11.5 - 1934), and

Gravity of Petroleum and Petroleum Products by Means of the Hydrometer (D 287 - 37; A.S.A. Z11.31 - 1937).

VI. WITHDRAWAL OF TENTATIVE STANDARDS

The committee recommends that the Tentative Method of Test for Expressible Oil and Moisture in Paraffin Waxes (D 308 - 29 T)[21] be withdrawn. The recommendation originated in Subcommittee III on Paraffin Wax (L. C. Beard, Jr., chairman) after further cooperative work had demonstrated that the method does not give satisfactory results and is not susceptible to improvement.

VII. TENTATIVE STANDARDS CONTINUED AS TENTATIVE

The following tentative standards have remained in the tentative status for a period of three years or longer without revision:

Tentative Method of Test for Neutralization Number of Petroleum Products and Lubricants (D 188 - 27 T), and

Tentative Method of Test for Sulfur in Petroleum Oils by Lamp Method (D 90 - 34 T).

These tentative standards may be revised before being recommended for adoption as standard as a result of further work by the responsible subcommittees. It is accordingly recommended that they be continued as tentative.

VIII. STANDARDS CONTINUED WITHOUT REVISION

Seven standard methods have been published for a period of six years or more without revision, as follows:

Standard Methods of Test for:

Autogenous Ignition Temperatures of Petroleum Products (D 286 - 30),

Burning Quality of Mineral Seal Oil (D 239 - 30),

Flash and Fire Points by Means of Open Cup (D 92 - 33),

Melting Point of Petrolatum (D 127 - 30),

Sampling Petroleum and Petroleum Products (D 270 - 33),

Detection of Free Sulfur and Corrosive Sulfur Compounds in Gasoline (D 130 - 30), and

Water in Petroleum Products and Other Bituminous Materials (D 95 - 30).

These methods have been considered by the committee and require no revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 79 voting members, with the results shown in Table II.

This report has been submitted to letter ballot of the committee which consists of 79 voting members; 64 members returned their ballots, of whom 63 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

T. A. BOYD,
Chairman.

R. P. ANDERSON,
Secretary.

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[21] *Proceedings*, Am. Soc. Testing Mats., Vol. 29, Part I, p. 682 (1929); also 1938 Book of A.S.T.M. Tentative Standards, p. 805.

EDITORIAL NOTE

Subsequent to the annual meeting, Committee D-2 on Petroleum Products and Lubricants presented to the Society on August 24, 1939, through Committee E-10 on Standards a revision of the Tentative Specifications for Fuel Oils (D 396 - 38 T). This revision was accepted by Committee E-10 and the specifications in their revised form appear in the 1939 Book of A.S.T.M. Standards, Part III.

REPORT OF SECTION ON GUM

Technical Committee A on Gasoline

An earlier report[1] of this section proposed a method for determination of gum content and introduced the subject of gum stability. Since that time an extensive amount of work has been done on accelerated methods of determining gum stability and upon the relation of such tests to storage behavior.

A metal bomb, suitable for making oxidation tests under pressure at approximately 212 F., was designed and one of these bombs was obtained by each member of the section. In developing this design, advantage was taken of the experience of various laboratories on the use of metal bombs, attention being given to such factors as mechanical suitability, ease of cleaning, temperature lag, and ratio of oxygen to sample. At the outset, a reference method for carrying out the test was drawn up, which involved use of a temperature of 211 F. and initial pressure of 100 lb. A comprehensive exploratory program was undertaken, in which a number of variables were studied. Altogether, about 25 gasolines were included in this work and a large number of cooperative tests were carried out. The low-pressure induction-period test[2] (Voorhees method) and the copper-dish test were also studied. The present report summarizes the work of the last 5 yr.

Exploratory Oxidation Tests

Criteria of Break.—A common method of expressing the results of accelerated oxidation tests on gasoline is in terms of the induction period, which is the time from the start of the oxidation test until a sharp increase in rate of oxidation, or "break," is reached. Various methods of defining the break point were used, including a total drop of 5 or 10 lb. and a rate of pressure drop of 2 lb. in 15 min. Also, gum contents were determined at different lengths of time of oxidation.

The results obtained indicated that the use of the induction period, as defined by the rate of pressure drop, is the most satisfactory from the standpoint of reproducibility. Other findings were as follows:

1. The determination of amount of gum formed at a fixed time gives very erratic results.
2. The amount of gum present at the break point, however defined, is not a fixed value for different gasolines but varies with the stability of the gasolines.
3. A significant temperature rise was noted in the gasoline at the break point. This may amount to as much as 10 F. and is the result of rapid oxidation of the gasoline. This phenomenon tends to interfere with the use of the method as an isothermal accelerated test but, on the other hand, it tends to accentuate the break point and make the use of the induction period criterion a practical one.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part I, p. 407 (1932).

[2] V. Voorhees and J. O. Eisinger, "The Significance of Gum in Gasoline," *Proceedings*, Am. Petroleum Inst., Vol. 10, Part II, p. 169 (1928).
T. H. Rogers, J. L. Bussies and P. T. Ward, "Gum Formation in Gasoline. I. Measurement of Gum Stability in Gasoline," *Industrial and Engineering Chemistry*, Vol. 25, pp. 397–402 (1933).

Temperature.—The induction periods of several gasolines, including some containing an inhibitor, were determined at four temperatures over the range 185 to 225 F. These data formed a straight line when log of induction period was plotted against reciprocal of the absolute temperature, and the curves for the different gasolines were closely parallel. This is in accordance with other published data,[3] showing that the relation between the induction period and temperature may be expressed as follows:

$$\log IP = A + \frac{B}{T}$$

When the induction period is expressed in minutes and temperature in degrees Rankine, the average value of B for the six gasolines studied was 10,300. The induction period is doubled for a decrease in temperature of approximately 13 F., showing that accurate temperature control is essential in the test.

Volume of Sample.—It was found that the volume of the sample used has but slight effect on the induction period. As between volumes of 100 and 110 ml., no perceptible difference was noted. Tests were also made with 50 ml. and 25 ml. of gasoline, the induction period being increased slightly as the volume of the sample was decreased. Although the induction period was not greatly affected by change in the volume of the sample, it was found that the amount of gum formed after a given time was much greater in the case of the smaller sample.

Pressure.—A substantial amount of work was done with varying initial pressure in the bomb test, inasmuch as some cases had been noted where there were marked differences in the ratio of results between the low-pressure Voorhees type of test and the bomb test. From a large amount of data obtained, Table I may be given as typical of the results. It will be noted that the effect of pressure is not very great, and that in the neighborhood of 100 lb., a few pounds variation will not have significant effect. The results show that the ratio between the low-pressure test and the high-pressure test increases as the induction period of a gasoline is increased by adding inhibitor.

TABLE I.—EFFECT OF PRESSURE ON INDUCTION PERIOD.

	Induction Period, min.								
	Control Gasoline			Inhibited[a]		Inhibited[b]		Inhibited[c]	
	Lab. 4	Lab. 6	Lab. 8	Lab. 6	Lab. 8	Lab. 4	Lab. 6	Lab. 4	Lab. 8
Bomb, 135-lb. initial pressure	105	180	190	230	215	220	235	270	365
Bomb, 100-lb. initial pressure	180	188	190	245	240	225	250	390	405
Bomb, 50-lb. initial pressure	210	195	217	290	290	270	267	465	475
Voorhees method	212	228	225	380	292	290	316	595	575
Ratio: $\frac{\text{Voorhees Method}}{\text{Bomb (100 lb.)}}$	1.18	1.20	1.18	1.55	1.18	1.30	1.23	1.53	1.42

[a] Inhibited with benzol aminophenol.
[b] Inhibited with alphanaphthol.
[c] Inhibited with hardwood creosote.

Effect of Glass Liner.—Tests were made with various gasolines, in which the results with and without a glass liner were compared. These tests showed that exposure of the gasoline to the metal had a slight accelerating effect, but this was not pronounced in any case.

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[3] J. W. Ramsay, "Gum Stability of Gasolines," *Industrial and Engineering Chemistry*, Vol. 24, pp. 539–542 (1932).
E. W. Aldrich and N. P. Robie, "The Gum Stability of Gasolines," *Journal*, Soc. Automotive Engrs., Vol. 30, pp. 198–207 (1932).

In general, the induction period was lowered by about 10 per cent by elimination of the liner, part of which may be accounted for by the decrease in temperature lag.

Purging and Shaking.—The reference procedure originally used consisted in filling with oxygen to a pressure of 125 lb., followed by purging and refilling twice and final adjustment of the pressure to 100 lb. Comparative tests showed that this procedure gave the same results as did a single filling without purging. Also related to this were tests in which the bomb was shaken thoroughly in order to attain saturation more quickly. In the shaking procedure, the liner was eliminated. Comparative tests are shown in Table II, and it will be noted that the induction period is decreased somewhat by shaking, although this decrease is of about the same order of magnitude as that obtained by elimination of the glass liner without the shaking procedure. The results serve, incidentally, to show the reproducibility obtained in various laboratories. As will be noted, the relationship between the two gasolines is about the same whether or not the shaking procedure is employed. It was, therefore, decided that the simple procedure of filling the bomb, adjusting the pressure, and allowing the bomb to stand quiescent after putting it in the bath should be adopted.

TABLE II.—EFFECT OF SHAKING ON INDUCTION PERIOD.

Laboratory	Induction Period, min.						Regular Bomb, Ratio D/E, Average	Shaking, Ratio D/E, Average	Voorhees Method, Ratio D/E, Average
	Sample D			Sample E					
	Bomb			Bomb					
	Regular	Shaking	Voorhees Method	Regular	Shaking	Voorhees Method			
1......	150	150	...	195	150	...	0.74	1.0	....
	150	150	...	210	150	...	....	....	....
3......	157	148	...	206	197	...	0.75	0.74	....
	155	145	...	210	198	...	....	....	....
4......	215	145	335	225	185	340	1.0	0.80	1.03
	215	150	355	205	180	320	....	....	....
			335	...	...	340	....	....	....
5......	180	165	484	240	210	438	0.75	0.75	1.12
	180	150	475	240	210	420	....	....	....
6......	208	163	355	234	225	365	0.83	0.71	1.03
	185	165	395	240	240	375	....	....	....
	190	...	375	230	...	355	....	....	....
			370	232	...	360	....	....	....
8......	188	168	...	243	228	...	0.78	0.74	....
	198	168	...	258	228	...	....	....	....
	198	168	...	243	228	...	....	....	....
9*.....	249	190	...	272	235	...	0.91	0.82	....
	237	188	...	265	226	...	....	....	....
10......	180	150	...	225	180	...	0.78	0.80	....
	180	150	...	240	195	...	....	....	....
11......	150	120	...	210	165	...	0.71	0.70	....
Grand Avg.	177	149	398	224	190	375	0.79	0.78	1.06

* Tests made in this laboratory were at 209 F, and are not included in the average.

STORAGE TESTS

The relation between accelerated gum stability and storage tests has been studied[4] extensively in various laboratories. Both the Voorhees method and the 100-lb. bomb test have been used, and the copper-dish test has also been employed in this connection. A general relationship between these accelerated and storage tests is brought out, but various discrepancies and departures from exact correlations have been noted. The object of the work of this section was not to cover completely the question of commercial storage of gasoline but to make a series of cooperative storage tests under a standard condition thought to be significant and to compare the results of these tests with accelerated tests. As predictive tests, the following were employed:

(*a*) *Bomb Test.*—The bomb test, as developed in the above described work

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[4] T. H. Rogers, J. L. Bussies and P. T. Ward, *loc. cit.* Carl Winning and R. M. Thomas, "Predicting Stability of Gasolines to Aging," *Industrial and Engineering Chemistry*, Vol. 25, pp. 511–516 (1933).
C. G. Dryer, J. C. Morrell, G. Egloff and C. D. Lowry, Jr., "Inhibitors in Cracked Gasoline. III. Storage Stability as Related to Induction Period and Critical Oxidation Potential," *Industrial and Engineering Chemistry*, Vol. 27, pp. 15–20 (1935).

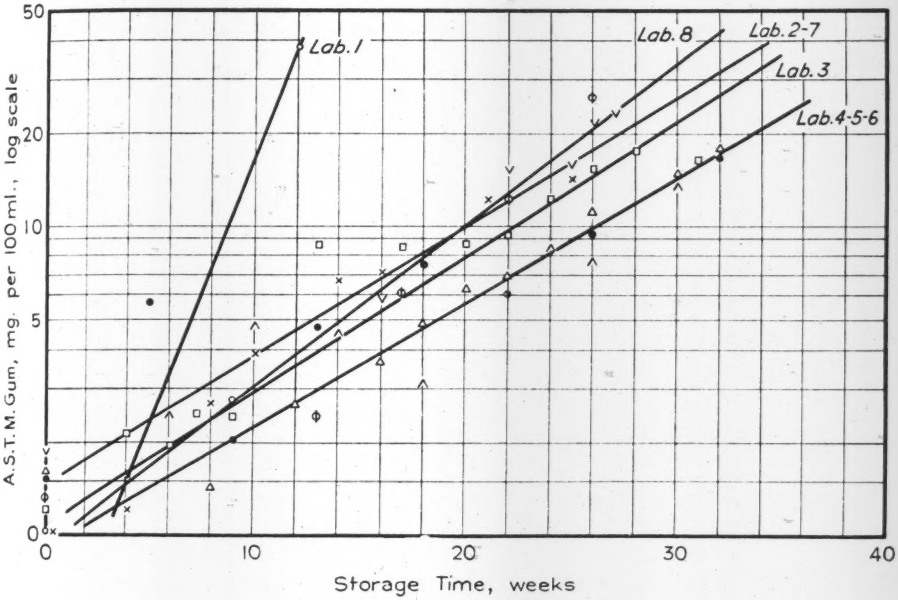

FIG. 1.—A.S.T.M. Gum Content *versus* Storage Time, Sample C-1.

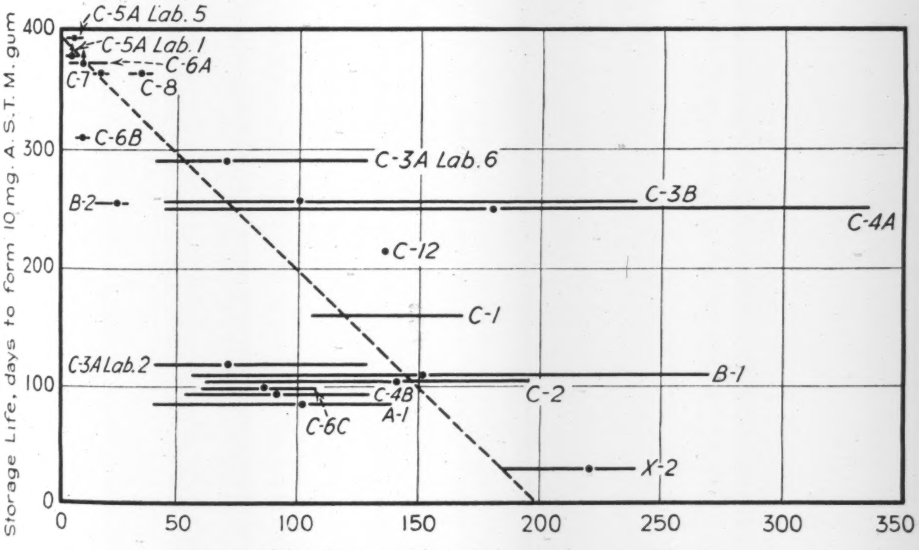

FIG. 2.—Storage Stability *versus* Copper Dish Gum.

and as now proposed as a tentative method.[5]

(*b*) *Voorhees Method.*—The Voorhees method, in which the following variations from the published[4] procedure were used: The flask was not shaken; a 50-lb. recording gage was used, and the break point was taken as the point at which a pressure drop of 0.58 lb. in 30 min. occurs; 10 min. were subtracted from the observed induction period to allow for temperature lag.

(*c*) *Copper-Dish Test.*—The copper-dish test following the procedure[6] which is employed in a number of laboratories.

TABLE III.—SUMMARY OF ACCELERATED AND STORAGE TESTS.

Gasoline	Nature	Stored By	Grand Average			
			Induction Period, min.		Copper Dish, mg.	Storage Life, days
			Bomb	Voorhees		
A-1	Cracked, sweetened	All labs.	56	53	100	85
B-1	Cracked, sweetened	All labs.	93	116	150	110
C-1	Cracked, sweetened	All labs.	192	251	130	160
B-2	B-1 + straight-run	Lab. 4	85	108	25	255
C-7	B-2 + inhibitor	Lab. 4	174	250	20	365+
C-3a	B-1 + inhibitor	Lab. 6	205	330	70	290
C-3a	B-1 + inhibitor	Lab. 2	205	330	70	120
C-3b	B-1 + inhibitor	Lab. 8	172	263	100	255
C-4a	C-3b + Ethyl Fluid	Lab. 8	161	228	180	255
C-2	C-1 + Ethyl Fluid	Lab. 7	156	254	140	105
C-4b	C-3a + Ethyl Fluid	Lab. 2	130	267	90	100
C-5a	Acid treated	Lab. 1	271	369	5	365+
C-5a	Acid treated	Lab. 5	271	369	5	385
C-6a	Gray process	Lab. 1	390	641	10	365+
C-6b	Gray process	Lab. 5	250	395	10	310
C-6c	Gray process	Lab. 3	96	83	85	100
C-8	Finished gasoline	Lab. 3	238	302	35	365+
X-2	Reformed gasoline	Lab. 7	39	32	220	30
X-3-2	Cracked, sour	Lab. 6	170	230	230	150
C-12	Cracked, X-3-2, sweetened	Lab. 6	160	195	135	215

The storage tests were carried out in brown glass bottles of approximately 1-gal. capacity. These were maintained at a temperature of 90 F. in a water bath, provision being made for access of air by placing a small capillary tube in the cork stopper. One set of tests was carried out in glass with no catalyst or water present. A similar test was made in which 250 ml. of distilled water and a steel strip were placed in the bottle. The ratio of metal surface to volume of gasoline corresponded roughly to that obtained in a 50-gal. barrel.

Three basic gasolines were used and the above storage tests were carried out in eight laboratories. The gasolines were all-cracked stocks which had been sweetened with a doctor solution. With these stocks as the basis, other samples were prepared by blending, addition of an inhibitor, tetraethyl lead, etc. Also, several other gasolines of entirely different sources were included in the series. The latter groups of modified gasolines were tested in only one or two laboratories, samples of the initial stock being checked in several laboratories by the accelerated tests.

In general, a reasonably good agreement in storage results was obtained in the different laboratories. Figure 1 gives, as an example, all of the test results obtained on one of the gasolines. The data from the separate laboratories show a linear relationship between the logarithm of gum content and time of storage. In view of this method of plotting, the differences which are apparent in low gum contents are not significant and the storage time to form 10 mg. of gum was, with one exception, in reasonably good agreement for all laboratories. Table III shows the averages of all the test results obtained. For the bomb tests, the average results are from eight laboratories in the case of the three basic gasolines and from four laboratories in the case of other gasolines. For the Voorhees tests, the average of results are from two to three laboratories and the averages for the copper-

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[5] This method was accepted as tentative by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part III.

[6] Federal Specification for Lubricants and Liquid Fuels (VV-L-791a), Section IV, Method 330.1.

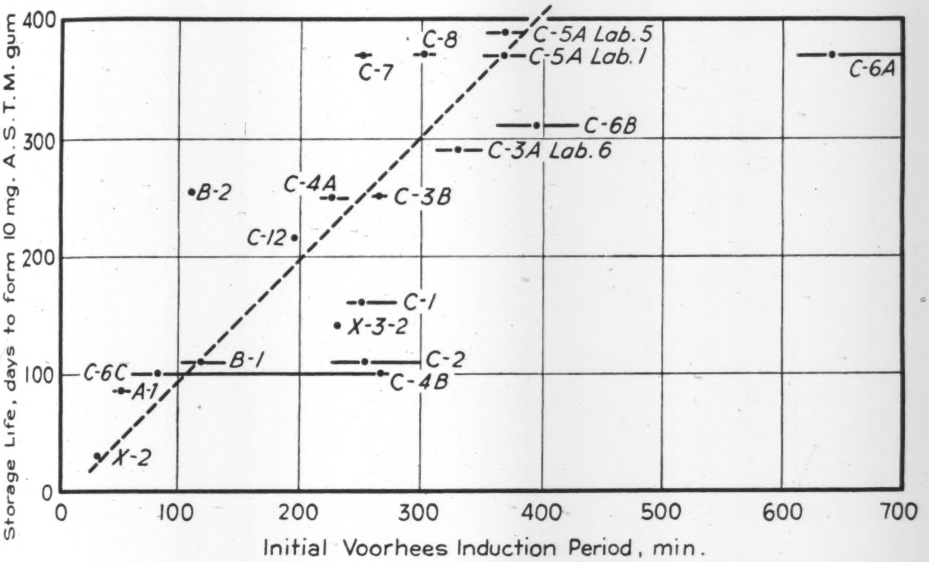

FIG. 3.—Storage Stability *versus* Voorhees Induction Period.

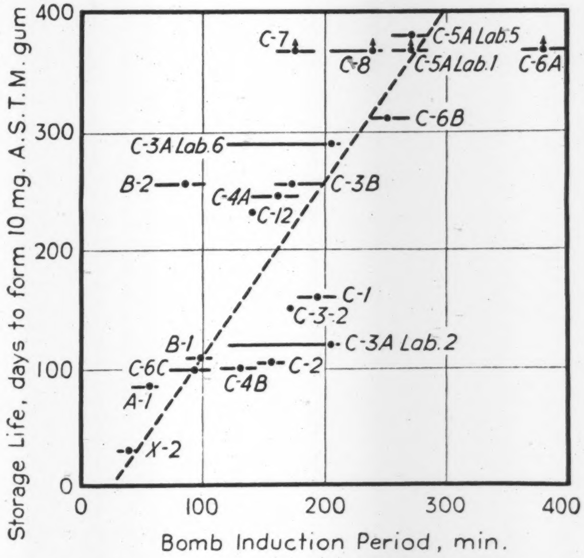

FIG. 4.—Storage Stability *versus* Bomb Induction Period.

dish tests from three to seven laboratories. In general, duplicate tests were made in each laboratory.

Figure 2 shows an attempted correlation between the storage life (to form 10 mg. of gum) and the copper-dish test. The length of the horizontal line shows the spread obtained in the tests by the different laboratories and the point indicates the grand average. It will be noted that there is a rough relationship, but that the variation in the copper-dish test is extremely wide, and at low copper-dish values, the relation of this test to storage behavior is quite indefinite. Figures 3 and 4 show the relationship between the Voorhees test and the bomb test, respectively, and storage life. The variation in the accelerated test results is not as serious as in the case of the copper-dish test. Each of the curves shows fair correlation between induction period and storage life, although there are various marked exceptions to a linear or smooth relationship. Figure 5 shows another type of correlation in which a combined factor, involving both the copper-dish test and the induction-period test are used. This correlation shows some improvement over those preceding, although the nature of the relationship and the unsatisfactory reproducibility of the copper-dish test do not justify recommendation of this as a standard procedure.

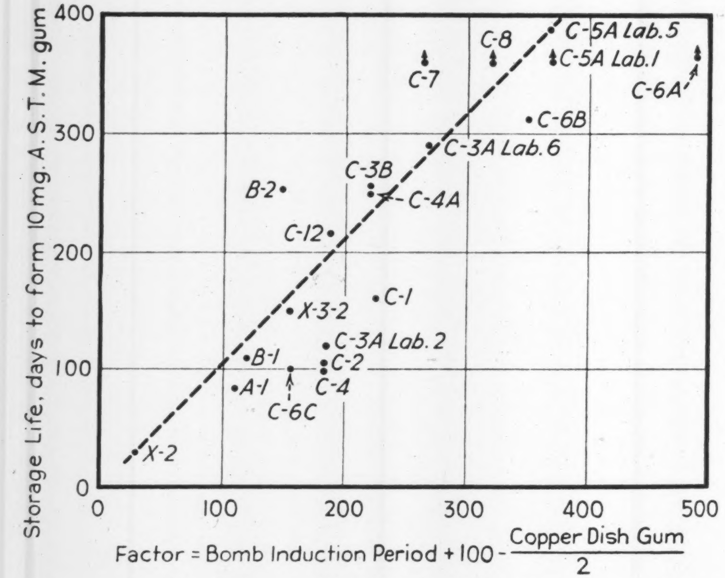

FIG. 5.—Storage Stability *versus* Induction Period — Copper Dish Factor.

The storage tests in the presence of water and metal strip showed rather marked acceleration over those of gasoline alone. The results, as might be expected, were more irregular. In general, the degree of acceleration was roughly the same for all the gasolines, so that it appears that the imposition of these added factors would not particularly affect the relative stability of the gasolines. In one set of tests, water alone and metal alone was added to gasoline. These tests show that the water did not accelerate but rather slightly inhibited the rate of gum formation. The effect of the metal strip was markedly to accelerate gum formation in line with the general tests already described.

In addition to these laboratory tests, two series of storage tests in automotive fuel tanks have been made with four of the gasolines. In the first series the temperature averaged 70.6 F., without great fluctuation. Summarized results are shown in Table IV. Owing to the rapid rate of gum formation in some tests, it is preferable to make comparisons of storage life using a relatively high gum content limit, 50 mg. being arbitrarily selected. These tests showed a much more rapid rate of gum formation than in glass bottles, in spite of the lower storage temperature. Except for the reversal in behavior of gasolines B-1 and C-1, the comparative order of stability of gasolines was the same as those in the glass-bottle storage tests. A finding which is quite significant is that new automotive fuel tanks cause much more rapid gum formation than do used tanks. In the second series of tests, storage extended from November, 1937, through the following summer at atmospheric temperature in Detroit. As shown in Table IV the rate of gum formation was much slower. The order of stability appears to correlate better with laboratory storage, but the variable temperature of storage precludes quantitative comparisons.

TABLE IV.—STORAGE TESTS OF GASOLINES IN AUTOMOTIVE FUEL TANKS.

Gasoline	Tank	Days to Form 50 mg. of Gum (A.S.T.M. Method D 381-36)[a,b]		
		1	2	3
SERIES A. STORAGE AT CORAL GABLES, FLA.				
C-1	Old tanks	105	140	...
C-1	New tanks	50	45	55
B-1	New tanks	100	60	90
C-3a	New tanks	140	85	...
C-5a	New tanks	175	225	...
SERIES B. STORAGE AT DETROIT, MICH.				
C-1	New tanks	300	—	290
B-1	New tanks	250	300	240
C-3a	New tanks	320	320	320+
C-5a	New tanks	more than 320 days		

[a] In the samples from the new tanks an oily residue of 5 to 15 mg. per 100 ml. was obtained consistently; this was subtracted from the total residue to obtain the actual gum content.

[b] Standard Method of Test for Gum Content of Gasoline (A.S.T.M. Designation: D 381), 1936 Book of A.S.T.M. Standards, Part II, p. 935.

CONCLUSIONS

It is the opinion of the members of this section that a standardized form of accelerated oxidation test should be made available to the industry. Storage tests have shown that, although such tests have some drawbacks, they are broadly significant with respect to gum formation. Of the two tests available, the data obtained do not show marked advantage in favor of one or the other. The bomb test is more generally used in the industry, and this type of test has accordingly been drawn up as a proposed Method of Test for Gum Stability of Gasoline[5] which is being recommended for publication as tentative.

TABLE V.—COMPARISON OF RESULTS BY VARIOUS BOMB TESTS.

Sample	Induction period, min.				
	Proposed Tentative Method[5]	Universal Oil Products Bomb[a]	Standard Oil of New Jersey Bomb[4]	Socony Vacuum Bomb[3]	Ethyl Gas Bomb[b]
A-1	55	45	66	45	...
B-1	93	101	130	93	...
C-1	192	258	182	203	...
C-3a	205	215	172	...	...
C-4a	161	230	188	...	...
C-5a	271	...	292	271	...
C-6	250	...	275	262	...
R	128	180	...	...	120
S	175	210	...	...	180
T	272	260	...	...	210
U	385	530	...	...	360+

[a] Gustav Egloff, J. C. Morrell, C. D. Lowry, Jr., and C. G. Dryer, "Inhibitors in Cracked Gasoline. I. Relation of Structure to Inhibiting Effectiveness," *Industrial and Engineering Chemistry*, Vol. 24, pp. 1375–1382 (1932).

[b] D. T. Flood, J. W. Hladky and Graham Edgar, "Chemical Nature of Gum-forming Constituents in Gasoline," *Industrial and Engineering Chemistry*, Vol. 25, pp. 1234–1239 (1933).

It should be pointed out that because

of differences in design, particularly as regards ratio of oxygen to sample, the results with this proposed method cannot be expected to agree with other bomb tests, even though the tests are carried out at the same temperature and pressure. Table V gives some data showing a comparison of results by A.S.T.M. bomb with those obtained by some other bombs which are in general use. These results are useful for general information but are not suitable for quantitative transposition of results from one bomb test to those of another.

Respectfully submitted on behalf of the section,

T. H. ROGERS,
Chairman.

REPORT OF SECTION ON TETRAETHYL LEAD IN GASOLINE

Technical Committee A on Gasoline

The section was formed about two years ago and shortly thereafter cooperative work was begun on the methods of analysis then commonly used for determining tetraethyl lead in gasoline. Serious shortcomings were found in these methods when applied to certain types of motor fuels. Shortly thereafter the attention of the section was called to a method developed by the Imperial Oil Co. of Canada in which the gasoline was refluxed with concentrated hydrochloric acid, the acid later being extracted and the lead salts therein later converted into lead nitrate. Preliminary examination of this method indicated that it had many advantages over the more commonly used methods but that it was time-consuming and not too well adapted to serve the needs of laboratories doing a large amount of this work.

TABLE I.—MEAN ERROR IN MILLILITERS OF TETRAETHYL LEAD PER GALLON.

Gasoline Samples	1	2	3	4	5	6
Actual lead content, ml. per gal	2.820	0.978	2.989	1.430	0.286	2.293
HCl-Reflux Method (proposed method)	−0.003	−0.010	−0.011	−0.006	−0.009	−0.039
HCl-Reflux Method (omitting heavy distillate)	−0.043	−0.014	−0.019	−0.008	−0.005	−0.032
Bromine Method	−0.043	−0.013	−0.062	−0.041	−0.041	−0.124
Imperial Oil Method (one laboratory)	−0.010	+0.022	−0.019	−0.030	+0.004	−0.053

The Ethyl Gasoline Corporation's laboratory developed a modification of this method employing the same general principle but using special equipment by means of which the time for the determination was cut down very materially and the precision increased. During the latter part of 1938 and early 1939, the section carried out cooperative tests on gasolines of known lead content covering a variety of chemical types using this modified method. The results of these cooperative tests were so satisfactory that at its meeting on January 16, 1939, the section voted to recommend the method to Technical Committee A for publication as a tentative standard. The test data are summarized in Table I.

Briefly the conclusions which can be drawn from the data are as follows:

The proposed method is the most accurate of any of the methods for extracting lead from gasoline. Followed by an accurate method for determining the extracted lead it gives results which average 0.7 per cent low and which are reliable to about 1.4 per cent when comparing an individual result with the mean of results from the same laboratory, or to 3 per cent when comparing results from different laboratories. Omission of the heavy distillate gives equally good results for gasolines of normal volatility (samples 3, 4, 5 and 6), but gives results having a higher negative error (about 2 per cent) for highly volatile gasolines, such as samples 1 and 2.

The bromine method (at present the most widely used of all methods) gives a greater error, averaging 3 per cent low, the error being particularly large (6 per cent) in the case of a highly cracked gasoline such as sample 6, and the variation between laboratories is higher (about 4 per cent).

The Imperial Oil Method, based on results from one laboratory, is almost as accurate as the proposed method. No other method examined gives as good results.

Finally, the proposed method gives more accurate and reproducible results than any other known method, and in addition lends itself readily to multiple determinations for laboratories carrying out large numbers of lead determinations. The apparatus employed, while special, is not expensive and involves no difficulties to the manufacturer.

Respectfully submitted on behalf of the section,

GRAHAM EDGAR,
Chairman.

APPENDIX I

PROPOSED METHOD OF TEST FOR NEUTRALIZATION NUMBER OF USED AVIATION OILS[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the Society, 260 S. Broad St., Philadelphia, Pa.

Scope

1. This method of test is intended to indicate in used aviation oils the presence of organic constituents having acid characteristics, and the contamination by mineral acids.

Neutralization Number

2. *Neutralization Number.*—Neutralization number is the weight in milligrams of potassium hydroxide required to neutralize one gram of oil.

Special Solutions Required

3. (*a*) *Aqueous Potassium Hydroxide (1 ml. = 5 mg. of KOH).*—Dissolve 5.1 g. of c.p. KOH in 1 liter of freshly boiled and cooled distilled water. Add a very small amount of barium hydroxide, sufficient to precipitate any potassium carbonate present. Standardize this solution against National Bureau of Standards' standard sample No. 39*e* of benzoic acid, using phenolphthalein as an indicator according to the following relation:

$$\frac{5 \text{ mg. of KOH}}{x \text{ mg. of benzoic acid}} = \frac{56.104 \text{ g. of KOH}}{122.048 \text{ g. of benzoic acid}}$$

$$1 \text{ ml. of KOH} = 10.88 \text{ g. of benzoic acid}$$

This weight of benzoic acid is required for standardization. The weight of benzoic acid should be dissolved in 50 ml. of 95 per cent alcohol and titrated cold. For the blank, use the same amount of alcohol and correct the titration.

Make necessary adjustments of the solution so that the value of potassium hydroxide equals 5 mg. of KOH per 1 ml.

NOTE.—Fit the solution bottle with a guard tube of soda lime to prevent access of carbon dioxide. The solution should be restandardized at necessary intervals.

(*b*) *Neutralized Ethyl Alcohol Solution.*—Prepare a solution of 1 part of 95 per cent pure ethyl alcohol and 1 part of distilled water. Bring the solution to the boiling point on a hot plate, remove and neutralize carefully with the aqueous potassium hydroxide, using phenolphthalein as the indicator. Do not use denatured alcohol.

(*c*) *Phenolphthalein Indicator.*—Dissolve 10 g. of the indicator in 1 liter of 95 per cent pure ethyl alcohol.

Apparatus

4. The apparatus shall consist of the following:

(*a*) *Erlenmeyer Flask.*—An Erlenmeyer flask of 250-ml. capacity, made of heat-resistant glass.

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[1] Under the standardization procedure of the Society, this proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants.

(*b*) *Burette.*—A burette of any convenient capacity (5 ml. or greater) graduated in 0.05 ml.

(*c*) *Balance.*—A platform balance accurate to at least 0.1 g.

(*d*) *Hot Plate.*—A hot plate capable of heating samples from room temperature to boiling within 5 min.

Procedure

5. (*a*) Weigh 20 ± 0.1 g. of a representative sample into an Erlenmeyer flask. Add 100 ml. of the neutralized ethyl alcohol solution, and 1 ml. of the phenolphthalein indicator. Agitate the mixture by vigorous swirling in the unstoppered flask, place on the hot plate, and heat to boiling. Agitate by swirling during the heating process at 30-sec. intervals or more frequently, if necessary, to prevent bumping. When boiling, agitate the mixture by vigorous swirling for a period of 1 min. Then introduce 0.1 ml. of the KOH solution, agitate by vigorous swirling for 5 sec. (or longer if necessary to obtain thorough mixing as indicated by the absence of red streaks in the alcohol layer) and let the flask stand until the oil and alcohol have separated sufficiently to permit a clear observation of the color of the alcohol layer. The color of this layer may best be observed by raising the flask and tipping at an angle. For satisfactory observations, good daylight or a daylight lamp should be employed. Do not allow the flask to stand between agitation and the next addition of alkali longer than is required for observation of the alcohol layer. If this layer is not pink, continue the titration as rapidly as possible by the addition of 0.1-ml. portions of the alkali, agitating and settling as described above until a pink color is observed. Then reheat the mixture to boiling, and agitate by swirling for an additional 1 min. If the color persists, the total amount of alkali added represents the amount required to neutralize the acid contained in 20 g. of the oil. If the color disappears, add alkali in 0.1-ml. portions, agitating for 5 sec., reheating to boiling, and agitating for 30 sec. after each addition, until, on settling, a *faint* pink color is observed. It is important to make a careful observation of any color change in the alcohol layer as the faint pink color may be masked by color from oil dissolved in the alcohol. In all cases, carry the titration a little beyond the first pink coloration to ascertain whether the true end point has been reached. If the addition of a small amount of alkali increases the intensity of the pink color, the point at which the color change was observed represents the end point and the quantity of alkali added to the solution to bring about this first change or faint pink color shall be recorded as the number of milliliters of alkali required to neutralize 20 g. of the oil.

(*b*) *Calculation.*—Calculate the neutralization number of the oil as follows:

$$\text{Neutralization number} = \frac{\text{ml. of KOH used} \times \text{KOH per ml. of solution}}{\text{wt. of oil}}$$

Precautions

6. Because of the difficulties in obtaining reproducible results on neutralization numbers of used aviation oils when determinations are made by different laboratories, close attention to details is required, particularly the following:

(*a*) Adhere exactly to the time periods specified for agitation, using a stop watch.

(*b*) Be sure that the mixture is actually boiling when boiling is specified.

(*c*) Swirl as vigorously as possible without spilling the liquid. The periods of time of agitation specified are based on vigorous swirling and the results may be affected if gentle swirling is used.

(*d*) Take a faint pink color as the end point, the depth of this color to be as nearly comparable as possible with the faint pink color customarily taken as the end point in quantitative titrations of acids and bases.

(*e*) Allow sufficient time in the last portion of the titration for separation of the oil and alcohol layers to insure that the oil particles in the alcohol layer are not preventing the observation of the color change.

APPENDIX II

PROPOSED SPECIFICATIONS FOR AVIATION GASOLINE[1]

These are proposed specifications and are published as information only. Comments are solicited and should be addressed to the Society, 260 S. Broad St., Philadelphia, Pa.

At the request of the Air Transport Association of America, the Survey Division of the Cooperative Fuel Research Committee in 1938 made a study of the score or more of the then existing aviation gasoline specifications. This group, representing the leading air line operators, engine manufacturers, and petroleum refiners, reached agreement on five specifications which it believed would meet adequately the requirements of present-day engines. The subject was then referred to the American Society for Testing Materials. When there was question as to the relative merits of any item of specification, the limits retained were invariably in accord with current practice. In a number of cases no reliable data are available at this time to define the appropriate limits for satisfactory operation and investigations are now in progress to obtain such data. At present these specifications are restrictive of potentially suitable fuels which can be included, provided volatility limits can be expanded and other controversial restrictions eased or eliminated as a result of research now in progress.

Particular attention is called to Notes 1, 2, 3, and 4 relating to requirements for tetraethyl lead content, volatility, gum, and acid heat which are the principal controversial items.

Scope

1. (*a*) These specifications are for the use of purchasing agencies in formulating specifications for purchases of aviation gasoline under contract.

(*b*) These specifications are not a definition of aviation gasoline, nor do they include all types of fuel satisfactory for spark-ignition aviation engines. Certain equipment or conditions of use may require fuels having special characteristics.

Grades

2. Five grades of aviation gasoline are provided, varying chiefly as to octane number. The grades are designated by their respective A.S.T.M. octane numbers as follows:

Grade 73
Grade 80
Grade 87
Grade 90
Grade 95

General

3. These specifications state the required properties of gasoline at the time and place of delivery in bulk.

Detailed Requirements

4. The five grades of aviation gasoline shall conform to the requirements prescribed in Table I.

Methods of Testing

5. The properties enumerated in Table I shall be determined in accordance with the following methods of testing:

(*a*) *Octane Number.*—Standard Method of Test for Knock Characteristics of Motor Fuels (A.S.T.M. Designation: D 357).[2]

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[1] Under the standardization procedure of the Society, these proposed specifications are under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants.

[2] 1939 Book of A.S.T.M. Standards, Part III, p. 170.

TABLE I.—REQUIREMENTS FOR AVIATION GASOLINE.

	Grade 73	Grade 80	Grade 87	Grade 90	Grade 95
Octane number, min.	73	80	87	90	95
Tetraethyl lead, ml. per gal.:					
max.	none	2.0	3.0	4.0	4.0
min. (Note 1)	......	....	....	3.5	3.5
Color	not darker than +21	blue	blue	blue	blue
Requirements for All Grades					
Distillation temperature, max., deg. Fahr. (Note 2):					
10 per cent evaporated	158				
50 per cent evaporated	212				
90 per cent evaporated	257				
Sum of 10 and 50 per cent evaporated temperatures, min. deg. Fahr.	307				
Distillation recovery, min., per cent	97				
Distillation residue, max., per cent	1.5				
Distillation loss, max., per cent	1.5				
Acidity of distillation residue	neutral				
Vapor pressure, max., psi	7.0				
Corrosion:					
Copper strip	no gray or black discoloration				
Copper dish	no gray or black discoloration; residue on evaporation of 100 ml. not to exceed 5 mg.				
Gum, accelerated, max., mg. per 100 ml. (Note 3)	6				
Sulfur, max., per cent	0.10				
Freezing point, max., deg. Fahr.	−76				
Water tolerance	volume change not to exceed ±2 ml.				
Acid heat, max., deg. Fahr. (Note 4)	15				
Calorific value (higher), min., B.t.u. per lb. (optional requirement)	19 740				

NOTE 1: *Tetraethyl Lead.*—It will be noted that a minimum lead content is specified for the 90 and 95 grades. This minimum of 3.5 ml. per gal. was included because investigations by the Aviation Fuels Division of the Cooperative Fuel Research Committee[3] indicate that a minimum content of tetraethyl lead provides greater freedom from detonation in a full-scale engine than does a gasoline of lower tetraethyl lead content, but the same A.S.T.M. octane number. In other words, in the absence of an adequate laboratory knock-test method it is considered necessary that A.S.T.M. octane numbers should be qualified in accordance with the lead content of the gasoline in the 90 to 95 range. At present investigations are under way to develop a knock test for aviation gasoline which will correlate with full-scale engine operation without qualifying statements as to composition.

NOTE 2: *Volatility.*—The Cooperative Fuel Research Committee has organized a series of research projects to study the subject of aviation-gasoline volatility requirements with the object of determining: (*a*) those factors which dictate engine performance as affected by fuel volatility, and (*b*) the quantitative limits to be assigned to these factors throughout the distillation range. These findings, which may indicate the desirability of changes, will be reported to the Society.

NOTE 3: *Acid Heat.*—The object of including the maximum acid-heat requirement is to eliminate certain possible types of fuels which would meet other items of the specifications but might still be unsatisfactory in service from the standpoint of those difficulties in operation usually attributable to gum. Acid heat is recognized as being a quite indirect method of evaluation and a composition-limiting item. It is further realized that while it eliminates certain undesirable fuels it may also eliminate fuels which would be satisfactory. This subject is being studied by the Society in the hope that a more direct method of solving this problem may be obtained.

NOTE 4: *Gum.*—The accelerated gum test, as described, does not provide for a bomb of specific design and dimensions. This is a shortcoming, since these factors affect the heat transfer through the bomb and influence the results which will be obtained. The Tentative Method of Test for Gum Stability of Gasoline (A.S.T.M. Designation: D 525) of the American Society for Testing Materials[4] is intended primarily for automobile gasoline, but the Society will undertake an investigation of the applicability of this method and apparatus to aviation gasolines making such changes in technique as may be indicated. The method and requirement for gum stability prescribed in these specifications should therefore be considered only as a temporary expedient.

(*b*) *Tetraethyl Lead.*—Tentative Method of Test for Tetraethyl Lead in Gasoline (A.S.T.M. Designation: D 526).[5]

(*c*) *Color.*—Standard Method of Test for Color of Refined Petroleum Oil by Means of Saybolt Chromometer (A.S.T.M. Designation: D 156).[6]

(*d*) *Distillation.*—Standard Method of Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products (A.S.T.M. Designation: D 86).[7]

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[3] Rating Aviation Fuels in Full-Scale Aircraft Engines, Report of Cooperative Fuel Research Committee, H. K. Cummings. *Journal*, Soc. Automotive Engrs., December, 1938, Vol. 43, No. 6, pp. 497 to 503.

[4] 1939 Book of A.S.T.M. Standards, Part III, p. 611.

[5] *Ibid.*, p. 630.

[6] *Ibid.*, p. 106.

[7] *Ibid.*, p. 117.

(*e*) *Acidity of Residue.*—F.S.B. Method No. 510.2 as described in the Federal Specifications for Lubricants and Fuels; General Specifications (Methods for Sampling and Testing) (VV-L-791a).

(*f*) *Vapor Pressure.*—Tentative Method of Test for Vapor Pressure of Petroleum Products (Reid Method) (A.S.T.M. Designation: D 323).[8]

(*g*) *Corrosion*:

COPPER STRIP.—Standard Method of Test for Detection of Free Sulfur and Corrosive Sulfur Compounds in Gasoline (A.S.T.M. Designation: D 130).[9]

COPPER DISH.—F.S.B. Method No. 530.11 as described in the Federal Specifications for Lubricants and Fuels; General Specifications (Methods for Sampling and Testing) (VV-L-791a).

(*h*) *Gum* (*Accelerated Aging Test with Oxygen*).—Immerse sufficient, clean steel, (S.A.E. No. 1020) tubing $\frac{1}{4}$ in. in diameter (strips twisted into a spiral so that flat contact is avoided may be used) to furnish 35 sq. in. of exposed surface in 200 ml. of the finished gasoline in an 8-oz. oil sample bottle. Cover the bottle loosely to prevent the ingress of foreign matter and place in a dry bomb with the bomb and contents at room temperature. Fill the bomb with oxygen to a pressure of 95 to 100 psi., then allow the oxygen to escape to flush out air. Repeat the operation. Charge the bomb with oxygen to a pressure of 95 to 100 psi. for a third time, close the charging valve and disconnect the bomb from the oxygen charging line. Immerse the bomb and contents for 5 hr. in a steam or water bath heated to 208 to 212 F. (97.8 to 100 C.). At the completion of the 5-hr. period, remove the bomb and cool rapidly with water. Release the pressure gradually, remove the bottle and pour out the contents. To remove any insoluble gum, wash the bottle twice with 20 ml. of a mixture of equal parts of acetone and benzene of laboratory reagent grade. Add these washings to the oxidized sample, shake and filter the mixture. Evaporate one-half of the oxidized sample and washings to dryness on a steam bath in accordance with the procedure for corrosion (copper dish) referred to in Paragraph (*g*), except that a weighed glass dish shall be used. Place the dish in an electric air oven maintained at 230 ± 9 F. (110 ± 5 C.). After 2 hr. in the oven, place the dish in a desiccator containing anhydrous calcium chloride, cool to room temperature, and weigh. The difference between the original and final weights of the dish is the weight of the gum content. Express as milligrams per 100 ml.

If the amount of residue exceeds 6 mg. and the fuel contains tetraethyl lead, the residue may be analyzed for lead compounds. If lead compounds are found, the weight of lead chromate ($PbCrO_4$) multiplied by 0.80, or the weight of the lead sulfate ($PbSO_4$) multiplied by 0.85 may be deducted from the total weight of the residue.

NOTE: *Caution.*—Avoid exposing the sample to daylight prior to and during this test. At the end of the test no visible precipitate shall be present in the test bottle.

(*i*) *Sulfur.*—Tentative Method of Test for Sulfur in Petroleum Oils by Lamp Method (A.S.T.M. Designation: D 90).[10]

(*j*) *Freezing Point.*—F.S.B. Method No. 141.1 of the Federal Specification for Lubricants and Liquid Fuels; General Specifications (Methods of Sampling and Testing) (VV-L-791a).

(*k*) *Water Tolerance.*—Shake vigorously for at least 2 min. 80 ml. of the finished gasoline in a glass-stoppered graduate with 20 ml. of distilled water at room temperature. On settling after shaking, the volume of the aqueous layer shall not have increased or decreased by more than 2 ml.

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[8] 1939 Book of A.S.T.M. Standards, Part III, p. 637.
[9] *Ibid.*, p. 206.
[10] *Ibid.*, p. 626.

(*l*) *Acid Heat.*—Standard Method of Test for Acid Heat of Gasoline (A.S.T.M Designation: D 481).[11]

(*m*) *Calorific Value* (*Lower*).—Determine the heat of combustion (higher or gross value) in an oxygen-bomb calorimeter or in a properly standardized calorimeter of the Junkers type and make suitable correction for the latent heat of vaporization of water formed during the combustion of the fuel to obtain the heat of combustion (lower or net value). For referee tests, use an oxygen-bomb calorimeter and the procedure described in the Standard Method of Test for Thermal Value of Fuel Oil (A.S.T.M. Designation: D 240) of the American Society for Testing Materials[12] modified for volatile fuel as follows:

PREPARATION OF SAMPLE AND BOMB.—Fill a dry, weighed, gelatin capsule of suitable size with dry cotton fiber, weigh the capsule again and record the weight of gelatin and cotton. Fill the capsule by immersing it in the fuel and closing it under the surface. Dry the outside of the capsule, weigh the capsule immediately, and record the weight of the fuel. Wrap the ignition wire around the capsule three or four times and place the capsule immediately in the bomb.

PROCEDURE.—Fill the bomb with oxygen at 30 atmospheres. Repeat the test, if traces of sooty deposit or odor of unburned fuel are noticed when the bomb is opened after combustion. Deduct the heat of combustion of the gelatin and cotton from the total heat developed.

CALCULATION OF LOWER OR NET HEAT VALUE.—Any suitable method may be used for determining the water formed during the combustion for correcting the heat of combustion for the latent heat of vaporization of the water. However, for any referee tests use the method described in the paper on "Determination of Carbon and Hydrogen in Gasoline and Other Volatile Liquids,"[13] to determine the weight of water formed by combustion of each pound of fuel. The heat of combustion (lower or net value) per pound of fuel shall be considered as equal to the heat of combustion (higher or gross value) minus the weight, in pounds, of water per pound of fuel multiplied by 1050.

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[11] 1939 Book of A.S.T.M. Standards, Part III, p. 83.

[12] *Ibid.*, p. 210.

[13] H. Levin and C. Uhrig, *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 9, 326 (1937).

REPORT OF SECTIONAL COMMITTEE
ON
PETROLEUM PRODUCTS AND LUBRICANTS

ASA PROJECT: Z11

Sectional Committee Z11 on Petroleum Products and Lubricants held one meeting during the year: in Atlantic City, N. J., on June 30, 1938.

Progress is being made in the preparation of the several sections of the summary of work in the field of petroleum products and it is expected that the publication of the complete summary can proceed shortly. The publication, to be entitled "Evaluation of Petroleum Products," will comprise the following papers:

"Lubricating Oils," by J. C. Geniesse, Atlantic Refining Co.,
"Petroleum Lubricating Greases," by M. B. Chittick, The Pure Oil Co.,
"Gasoline," by T. A. Boyd, General Motors Corp.,
"Diesel Fuels," by T. B. Rendel, formerly Shell Oil Co.,
"Fuel Oils (Other than Diesel)," by H. V. Hume, Atlantic Refining Co., and
"The Status of Research on Fuels and Lubricating Oils for Spark Ignition Aircraft Engines," by S. D. Heron, Ethyl Gasoline Corp.

A change in the scope of the committee has been approved by letter ballot vote. The modified scope represents a more exact statement of the activities intended to be covered by the committee:

Scope.—The scope of the activities of the sectional committee shall include specifications, methods of test, and nomenclature relating to crude petroleum and petroleum products (products derived in whole or in large part from petroleum) other than asphalts, road oils, paint thinners, and electrical insulating materials.

The Study Committee on Boundary Lubrication (J. C. Geniesse, chairman) prepared a set of definitions of terms and concepts used in lubrication which are now before the sectional committee for comment and criticism.

The question of preparing specifications for gasoline for use in heavy-duty commercial vehicles, which has been assigned to Section V of Technical Committee A on Gasoline (A.S.T.M. Committee D-2), is being held in abeyance awaiting necessary basic information to be supplied by the interested members of the American Transit Association.

In line with its function as a reviewing body, the sectional committee has taken action during the year on five A.S.T.M. methods for reference to the American Standards Association for approval either as American standard or American tentative standard. At its meeting held during this annual meeting, on the recommendation of A.S.T.M. Committee D-2, action was taken to refer nine methods to the A.S.A. subject to letter ballot vote of the sectional committee. The recommendation concerning these standards will be submitted to Committee E-10 on Standards for approval.

Respectfully submitted on behalf of the sectional committee,

T. A. BOYD,
Chairman.

R. E. HESS,
Secretary.

REPORT OF COMMITTEE D-3
ON
GASEOUS FUELS

Committee D-3 on Gaseous Fuels held one meeting in 1938: in Atlantic City, N. J., on October 10. Two of the subcommittees met in Columbus, Ohio, in March, 1939, and other subcommittees met either in October, 1938, or at other times during the year.

While no tentative standards are available at present, active work is being continued on experimental comparisons of methods as shown in the following brief reports of the activities of the subcommittees:

Subcommittee I on Collection of Gaseous Samples (S. S. Tomkins, chairman).—Individual methods of sampling manufactured, natural, and liquefied petroleum gases are in process of preparation, and studies are being continued of sampling fundamentals.

Subcommittee II on Measurement of Gaseous Samples (H. S. Bean, chairman).—Work has been continued at the National Bureau of Standards during the year in the testing of small wet gas meters under various conditions of operation and at various rates. Tests have been made by one of the cooperating meter manufacturers to determine the gas and sealing-water temperatures in a wet meter as compared with room temperature for the purpose of deciding the best thermometer location for determining the metered gas temperature.

A paper has been prepared for presentation at the annual meeting discussing the experimental work on laboratory test meters during the last two years.[1]

Subcommittee III on Determination of Calorific Value of Gaseous Fuels (R. B. Harper, chairman).—A proposed standard method for the routine determination of the calorific value of gaseous fuels by means of the water-flow calorimeter was prepared and submitted to subcommittee members for review and criticism. Investigational work is now in progress by certain of the members regarding the suitability of the "humidity control" principle as an alternate means of dealing with heat loses. If the results justify its use, this method will be incorporated with the "humidity correction" method as a part of the proposed standard method for routine determinations of the calorific value of gaseous fuels.

Subcommittee IV on Determination of Specific Gravity and Density of Gaseous Fuels (E. F. Schmidt, chairman).—Investigation of various types of equipment in common use for specific gravity determination by the National Bureau of Standards has been the principal activity of this group for the past year. Twelve samples of such types of equipment have been submitted by manufacturers, and tests on them are now under way. It is proposed to devote the principal portion of the test work to gases having a range of specific gravities between

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[1] "Recent Experiments on Laboratory Wet Gas Meters," by Howard S. Bean and F. Charles Morey, see p. 1171.

0.32 and 0.72, the normal range for city gas. Numerous observations will be made on each instrument using various gases to secure data upon which to base the relative accuracy of the different types examined.

Subcommittee V on Determination of Impurities of Gaseous Fuels (E. F. Pohlmann, chairman).—A revised test method for the determination of the total sulfur in gaseous fuels by the referees' apparatus was submitted to subcommittee members for review. Tests are planned using different gases and rates to determine whether the burner as now designed will give satisfactory results under all conditions.

Methods covering the determination of organic sulfur in gaseous fuels by the catalytic hydrolysis method and for total sulfur in liquefied petroleum gases have been submitted to the committee members for their comment and criticism. A paper on the former method has been prepared for presentation at the annual meeting.[2] Studies are now in progress under the direction of subgroups covering the preparation of methods for the determination of impurities other than sulfur.

Subcommittee VI on Determination of Water Vapor Content of Gaseous Fuels (A. W. Gauger, chairman).—Study of the thermal conductivity method for the determination of water vapor was completed during the year. This method was not considered satisfactory either for field or precision work. A study has been initiated on two other methods. One involves measurement of color changes in solutions of cobalt salts in organic solvents upon addition of water; it should be completed within a year. The second involves radiation changes in the infra-red under the influence of water vapor. This appears to offer promise for precision work.

A paper on the "Determination of Water Vapor in Gaseous Fuels," by A. W. Gauger, F. C. Todd, and C. C. Haworth was presented at the Production and Chemical Conference of the American Gas Association in Rochester, N. Y., on May 24, 1939.

Subcommittee VII on Complete Analysis or Chemical Composition of Gaseous Fuels (Martin Shepherd, chairman).—Arrangements were made with a number of laboratories to conduct analyses of gaseous samples to be prepared by the National Bureau of Standards and supplied in standard containers. These will consist of carburetted water gas ranging from 500 to 600 B.t.u. per cu. ft., and natural gas ranging from 1100 to 1150 B.t.u. per cu. ft. Comparison of the various analyses obtained on identical samples will then be made.

This report has been submitted to letter ballot of the committee which consists of 32 members; 31 members returned their ballots, of whom 27 have voted affirmatively and 0 negatively.

Respectifully submitted on behalf of the committee,

A. C. FIELDNER,
Chairman.

R. M. CONNER,
Secretary.

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[2] "The Determination of Organic Sulfur in Gases by the Catalytic Hydrolysis Method," by Lawrence T. Jilk, see p. 1159.

REPORT OF COMMITTEE D-4

ON

ROAD AND PAVING MATERIALS

Committee D-4 on Road and Paving Materials has held two meetings during the past year: in Atlantic City on June 29, 1938, and in Columbus, Ohio, on March 9, 1939. During the year, the personnels of its many subcommittees were completely revamped in order to increase their activity and to assure their being composed of members most interested in the individual projects to be covered. This necessarily caused a temporary delay in the development of new specifications and methods of test but it is believed that the committee is now organized to proceed with much greater efficiency than before.

Considerable time was devoted to a critical review of the committee's numerous standards and tentative standards that have stood for a number of years without revision so that they might be brought up to date and their proper status determined. All of the recommendations in this report have to do with existing specifications and methods of test, although four new ones were developed which are published as information, as indicated below, pending their later submission to letter ballot of the committee.

Subsequent to the 1938 annual meeting, Committee D-4 presented to the Society through Committee E-10 on Standards proposed Tentative Specifications for Asphalt Plank (D 517 - 38 T), and a proposed revision of the Tentative Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 37 T), the latter in conjunction with Committee C-9 on Concrete and Concrete Aggregates. These recommendations were accepted[1] for publication on August 25, 1938, and appear in the 1938 *Proceedings*.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee B-9 on Size of Aggregates (E. F. Kelley, chairman).—As a result of cooperative tests by twelve laboratories, this subcommittee has developed a Proposed Method of Test for Sieve Analysis of Mineral Filler.[3] Its work was not completed in time for Committee D-4 to submit the method at this annual meeting but it has been referred to letter ballot of the committee for presentation to the Society later in the year through Committee E-10 on Standards since the test is referred to in certain revisions of standards recommended in this report. The results of the cooperative tests are given in the report appended hereto.

Subcommittee C-4 on Emulsified Asphalts (J. E. Myers, chairman).—This subcommittee has recently prepared Proposed Specifications for Emulsion for Use in Densely Graded Cold Asphaltic

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[1] In submitting these recommendations to Committee E-10 on Standards, Committee D-4 reported the following results of the letter ballot vote of a total of 79 ballots returned from a committee membership of 113: D 517 - 38 T, affirmative 69, negative 0, ballots marked "not voting" 8, ballots unmarked, 2; C 131 - 38 T, affirmative 74, negative 0, ballots marked "not voting" 5.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 916, 803 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 880, 629.

[3] See Editorial Note, p. 428.

Mixes. Satisfactory specifications for an emulsion suitable for such use are in great demand and Committee D-4 regrets that it is not prepared at this time to recommend the specifications to the Society for publication as tentative. However, it feels that the specifications prepared by Subcommittee C-4 may serve as a working basis for any new standard and they are accordingly published as information.[4] Attention is directed to the fact that these specifications embody two methods of test not yet standardized by the Society and to a modification of one of its present tentative methods of test.

Subcommittee D-3 on Expansion Joint Materials (H. M. Milburn, chairman).—For a number of years this subcommittee has been actively engaged in obtaining information which would serve as a reliable basis for recommending Specifications and for Methods of Testing Preformed Expansion Joint Filler for Concrete. Proposed specifications and methods of testing have now been prepared and referred to letter ballot of Committee D-4 for presentation to the Society later in the year through Committee E-10 on Standards.[5]

I. REVISIONS OF TENTATIVE STANDARDS

The committee recommends that the following three tentative specifications be revised as indicated below and continued as tentative:

Tentative Specifications for Crushed Stone for Bituminous Macadam Base and Surface Courses (D 192 – 38 T):[6]

Section 4.—In the table of crushed stone sizes, opposite "stone chips for seal coat" add the alternate size "4A" under group A, and the alternate size "5B" under group B.

Table II.—In the table of requirements for sieve analysis of group B sizes, add the following new requirements in their appropriate columns:

Size Number	5B
Nominal Size, Square Openings	No. 4 to ⅜ in.
Amounts finer than each sieve (square openings), per cent by weight:	
½ in.	100
⅜ in.	90 to 100
No. 4	0 to 20
No. 8	0 to 5

Tentative Specifications for Crushed Slag for Bituminous Macadam Base and Surface Courses (D 487 – 38 T),[7] to be revised exactly in accordance with the preceding recommendation for Specifications D 192 – 38 T.

Tentative Specifications for Crushed Stone for Bituminous Concrete Base and Surface Courses (D 486 – 38 T):[8]

Section 3.—In the table of physical properties, change the requirements for wear to read as follows by the addition of the italicized words:

	Stone for Use in Base Courses	Stone for Use in Surface and Binder Courses
Wear[a]		
(*Deval Method*)	not more than 7 per cent	not more than 6 per cent
(*Los Angeles Machine*)	*not more than 50 per cent*	*not more than 40 per cent*

[a] *Under these specifications it is expected that the engineer will designate one of these two methods and sets of test limits to be used on the project under consideration.*

Section 6 (b).—Change to read as follows by the addition of the italicized words:

Wear.—Either the Standard Method of Test for Abrasion of Rock by Use of the Deval Machine (A.S.T.M. Designation: D 2) *or Tentative Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (A.S.T.M. Designation: C 131), as may be required in accordance with Section 3 of these specifications.*

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[4] Committee D-4 reconsidered this recommendation at a meeting held during the annual meeting of the Society and decided to refer the publication as information of the specifications and methods of test involved to a further letter ballot of the committee accompanied by statements concerning them, the results to be referred to the Executive Committee of the Society. In the light of this subsequent letter ballot the Executive Committee authorized the publication of the methods in the ASTM BULLETIN, No. 101, December, 1939, p. 34, but withheld the specifications from publication.—ED.

[5] See Editorial Note, p. 428.

[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 933 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 922.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 930 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 919.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 927 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 916.

The committee also recommends that the following editorial changes be made in the two following tentative specifications:

Tentative Specifications for Asphalt Plank (D 517 - 38 T):[9]

Section 1.—Add a note to this section to read as follows:

NOTE.—Plain asphalt plank conforming to these specifications are also suitable for waterproofing protection where a solid bridge floor carries ballasted railroad track.

Section 2.—Change to read as follows by the addition of the italicized words and the omission of the words in brackets:

2. Asphalt plank shall be *formed by the extrusion of* a mixture of asphalt, fiber, and mineral aggregate [formed by extrusion] under sufficient pressure to expel the *entrapped* air and form a dense mass.

Tentative Specifications for Emulsified Asphalt ((Quick Setting) for Penetration and Surface Treatment) (D 401 - 36 T):[10]

Section 3.—Change the last sentence to read as follows by the addition of the italicized material and the omission of that in brackets:

Prior to any shipments being made on projects requiring 20,000 gal. or more [The] *a* sample shall be taken under the supervision of the purchaser, from [factory storage containing] *a lot of* not less than 20,000 gal. of the emulsified asphalt and shall be kept in a clean airtight sealed [glass or black iron] container at a temperature of not less than 4 C. (40 F.) until tested.

The committee has in addition completely revised the Tentative Specifications for Asphalt Filler for Brick Pavements (Blown Type) (D 241 - 26 T) which revision has been submitted to letter ballot of the committee for presentation to the Society later in the year through Committee E-10 on Standards.[5]

II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

Committee D-4 wishes to record its approval of the recommendation of Committee C-9 on Concrete and Concrete Aggregates that the Tentative Method of Test for Sieve Analysis of Fine and Coarse Aggregates (C 136 - 38 T)[11] be adopted as standard. This method of test is under the joint jurisdiction of the two committees.

The committee also recommends that the following ten tentative standards, with revisions in eight, as indicated below, be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Method of Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 36 T),[12]

Tentative Method of Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 36 T)[12]

Tentative Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 38 T):[11]

Section 2.—Change the sixth sentence to read as follows by the addition of the italicized words:

The cover shall be so designed as to maintain the cylindrical contour of the interior surface *unless the shelf is so located that the charge will not fall on the cover, or come in contact with it during the test.*

Section 3 (b).—Change the Note to this section from its present form: namely,

NOTE.—The limiting weight for each cast-iron or steel sphere permits the use of a charge consisting of a mixture of steel balls $1\frac{7}{8}$ in. and $1\frac{13}{16}$ in. in diameter. When steel spheres heavier than the prescribed weights are obtained, it is suggested that they be reduced in size by grinding. Cast-iron spheres, uniform in size, meeting these specifications are readily available.

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[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 916 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 880.

[10] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 866 (1936); also 1938 Book of A.S.T.M. Standards, p. 856.

[11] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 808, 803 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 636, 629.

[12] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, pp. 805, 808 (1936); also 1938 Book of A.S.T.M. Tentative Standards, pp. 651, 654.

to read as follows:

NOTE.—Steel spheres $1\frac{27}{32}$ in. in diameter and weighing 417 g. can be obtained from at least one manufacturer. If they are not readily available the next larger size ($1\frac{7}{8}$ in.) may be ground to size. Cast-iron spheres, uniform in size, meeting these specifications are available.

Tentative Specifications for Mineral Filler for Sheet Asphalt and Bituminous Concrete Pavements (D 242 – 26 T):[13]

Section 3.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

3. The mechanical analysis shall be determined in accordance with the [Tentative Method of Test for Sieve Analysis of Fine and Coarse Aggregates (A.S.T.M. Designation: C 136) of the American Society for Testing Materials, using only the No. 30, No. 80 and No. 200 sieves] *Tentative Method of Test for Sieve Analysis of Mineral Filler (A.S.T.M. Designation: D 546) of the American Society for Testing Materials.*

Tentative Methods of Testing Emulsified Asphalts (D 244 – 36 T):[14]

Section 6 (f).—Change the second sentence to read as follows by the addition of the italicized words:

The cover shall then be removed from the still and suitable portions of the residue shall be poured immediately *through a No. 50 sieve* into suitable molds and containers for making the required tests.

Delete the last sentence of the Note reading as follows:

Should the residue then appear granular or heterogeneous, the test shall be rejected and the distillation repeated as previously described with the exception that the still temperature at 500 F. (260 C.) shall be maintained for a longer time than 15 min. until the desired condition of the residue is obtained.

Tentative Specifications for Emulsified Asphalt (for Coarse Aggregate Plant Mixes) (D 397 – 36 T):[15]

Title.—Add the words "Medium Setting" before the word "Emulsified."

Section 1.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

1. These specifications cover *a medium consistency* emulsified asphalt for [coarse aggregate] plant mixes *with coarse aggregate, substantially all of which is retained on a* $\frac{1}{8}$*-in. sieve and with practically no material passing a No. 200 (74-micron) sieve.*

Section 3.—Make the same editorial change as recommended above in Section 3 of Tentative Specifications D 401 – 36 T.

Tentative Specifications for Emulsified Asphalt (for Retread and Coarse Aggregate Mixes) (D 398 – 36 T):[16]

Title.—Add the words "Medium Setting" before the word "Emulsified."

Section 1.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

1. These specifications cover *a low consistency* emulsified asphalt for retread [and coarse aggregate] mixes *with coarse aggregate, substantially all of which is retained on a* $\frac{1}{8}$*-in. sieve and with practically no material passing a No. 200 (74-micron) sieve.*

Section 3.—Make the same editorial change as recommended above in Section 3 of Tentative Specifications D 401 – 36 T.

Tentative Specifications for Emulsified Asphalt (Heavy Premix—Summer Grade) (D 399 – 36 T):[17]

Title.—Add the words "Medium Setting" before the word "Emulsified."

Section 1.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

1. These specifications cover *a high-consistency heavy-premix grade of* emulsified asphalt [heavy premix, summer grade]

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[13] *Proceedings*, Am. Soc. Testing Mats., Vol. 26, Part I, p. 868 (1926); also 1938 Book of A.S.T.M. Tentative Standards, p. 931.

[14] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 880 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 887.

[15] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 860 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 850.

[16] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 862 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 852.

[17] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 864 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 854.

for plant mix or patching with coarse aggregate, substantially all of which is retained on a ⅛-in. sieve and with practically no material passing a No. 200 (74-micron) sieve.

Section 3.—Make the same editorial change as recommended above in Section 3 of Tentative Specifications D 401 – 36 T.

Tentative Recommended Practice for Bituminous Paving Plant Inspection (D 290 – 28 T):[18]

Section 9 (a).—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

9. *(a)* Daily control samples of asphalt cement and mixtures shall be selected and, at the end of the day's work, forwarded to the laboratory [in a manner to arrive at the laboratory in the shortest possible time] *without delay.*

Section 15 (b).—Change the last sentence to read as follows by the addition of the italicized words and the omission of those in brackets:

Loss of fine [mineral matter through heating] *material in the drying process* shall be compensated for by the use of additional filler in proportioning.

Section 20.—Change from its present form: namely,

20. *Filler.*—A sample of the filler shall be thoroughly dried, 50 g. accurately weighed, and the amount passing the No. 200 sieve shall be determined in accordance with Sections 19 to 24, inclusive, of the Standard Methods of Sampling and Testing Portland Cement (A.S.T.M. Designation: C 77) of the American Society for Testing Materials. If any appreciable amount of filler is retained on the No. 200 sieve, the mechanical analysis of the coarser material shall be obtained in the same manner as in testing sand, see Section 19.

to read as follows:

20. *Filler.*—Samples of the thoroughly dry filler shall be tested in accordance with the Tentative Method of Test for Sieve Analysis of Mineral Filler (A.S.T.M. Designation: D 546) of the American Society for Testing Materials.[19]

Asphalt Plant Report.—In the table of gradings, first column, substitute "No. 4" for "¼ in.," and substitute "1½ in." for "1¼ in." wherever they appear.

III. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD

The tentative revisions[20] of the following standard method of test and three specifications are considered to be entirely satisfactory and the committee accordingly recommends that they be approved for reference to letter ballot of the Society for incorporation in the standards.

Standard Method of Test for Ductility of Bituminous Materials (D 113 – 35),[21]

Standard Specifications for:

Block for Granite Block Pavements (D 59 – 26),[21]

Block for Recut Granite Block Pavements (D 131 – 23),[21] and

Block for Durax Granite Pavements (D 132 – 23).[21]

IV. REVERSION OF STANDARDS TO TENTATIVE

Because of contemplated revisions, it is recommended that the following three standards[22] be reverted to tentative status:

Standard Methods of:

Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials, Including Some Material Survey Methods (D 75 – 22),

Sampling Bituminous Materials (D 140 – 25), and

Test for Loss on Heating of Oil and Asphaltic Compounds (D 6 – 33).[23]

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[18] *Proceedings*, Am. Soc. Testing Mats., Vol. 28, Part I, p. 956 (1928); also 1938 Book of A.S.T.M. Tentative Standards, p. 900.

[19] 1939 Book of A.S.T.M. Standards, Part II.

[20] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1332, 1330, 1331 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1698, 1696, 1697.

[21] 1936 Book of A.S.T.M. Standards, Part II, pp. 1058, 1005, 1007, 1009.

[22] 1936 Book of A.S.T.M. Standards, Part II, pp. 1092, 1088, 1071.

[23] See Editorial Note, p. 428.

V. WITHDRAWAL OF TENTATIVE STANDARDS

The following ten tentative specifications for asphalt cements have not been revised during the past thirteen years or longer. The committee does not consider them satisfactory for adoption as standard, and as it has not yet been able to reach an agreement upon their revision it recommends that they be withdrawn:

Tentative Specifications for:

Asphalt Cement, 10 to 15 Penetration, for the Manufacture of Asphalt Block (D 133 - 23 T),[24]

Asphalt Cement, 15 to 25 Penetration, for the Manufacture of Asphalt Block (D 134 - 23 T),[24]

Asphalt Cement, 25 to 30 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements (D 163- 23 T),[24]

Asphalt Cement, 30 to 40 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements (D 164 - 23 T),[24]

Asphalt Cement, 40 to 50 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements and as Filler for Brick and Block Pavements (D 99 - 26 T),[25]

Asphalt Cement, 50 to 60 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements and as Filler for Block Pavements (D 100 - 26 T),[25]

Asphalt Cement, 60 to 70 Penetration, for Use in Sheet Asphalt, Asphaltic Concrete and Asphalt-Macadam Pavements and as Filler for Block Pavements (D 101 - 26 T),[25]

Asphalt Cement, 85 to 100 Penetration, for Use in Asphalt-Macadam Pavements (D 102 - 24 T),[26]

Asphalt Cement, 100 to 120 Penetration, for Use in Asphalt-Macadam Pavements (D 103 - 24 T),[26] and

Asphalt Cement, 120 to 150 Penetration, for Use in Asphalt-Macadam Pavements (D 135 - 23 T).[27]

VI. STANDARDS CONTINUED WITHOUT REVISION

In order to determine whether they are in accord with present practice, the committee has reviewed the following standards, which have remained without revision for a number of years, and approves retaining these standards in their present form, with editorial corrections in four methods of test and one specification, as indicated below:

Standard Methods of:

Test for Abrasion of Rock by Use of the Deval Machine (D 2 - 33),

Test for Toughness of Rock (D 3 - 18),

Test for Determination of Bitumen (D 4 - 27),

Test for Specific Gravity of Road Oils, Road Tars, Asphalt Cements and Soft Tar Pitches (D 70 - 27),

Test for Specific Gravity of Asphalts and Tar Pitches Sufficiently Solid to be Handled in Fragments (D 71 - 27),

Test for Water in Petroleum Products and Other Bituminous Materials (D 95 - 30),

Float Test for Bituminous Materials (D 139 - 27),

Test for Proportion of Bitumen Soluble in Carbon Tetrachloride (D 165 - 27),

Test for Residue of Specified Penetration (D 243 - 36),

Standard Definitions of Terms Relating to Materials for Roads and Pavements (D 8 - 33),

Standard Method of Test for Penetration of Bituminous Materials (D 5 - 25):[28]

Section 4.—Change the Note to this section from its present form: namely,

NOTE.—The American Can Company's 3-oz. Gill style flat-bottom, seamless oint-

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[24] *Proceedings*, Am. Soc. Testing Mats., Vol. 23, Part I, pp. 719 to 723 (1923); also 1938 Book of A.S.T.M. Tentative Standards, pp. 858 to 864.

[25] *Proceedings*, Am. Soc. Testing Mats., Vol. 26, Part I, pp. 860 to 864 (1926); also 1938 Book of A.S.T.M. Tentative Standards, pp. 866 to 870.

[26] *Proceedings*, Am. Soc. Testing Mats., Vol. 24, Part I, pp. 920, 921 (1924); also 1938 Book of A.S.T.M. Tentative Standards, pp. 872, 874.

[27] *Proceedings*, Am. Soc. Testing Mats., Vol. 23, Part I, p. 730 (1923); also 1938 Book of A.S.T.M. Tentative Standards, p. 876.

[28] 1936 Book of A.S.T.M. Standards, Part II, p. 1080.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISIONS OF TENTATIVE STANDARDS			
Spec. for Crushed Stone for Bituminous Macadam Base and Surface Courses (D 192 - 38 T)	74	0	20
Spec. for Crushed Slag for Bituminous Macadam Base and Surface Courses (D 487 - 38 T)	68	0	26
Spec. for Crushed Stone for Bituminous Concrete Base and Surface Courses (D 486 - 38 T)	75	0	19
II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 36 T)	81	1	12
Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 36 T)	80	1	13
Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 38 T), as revised	73	5	16
Spec. for Mineral Filler for Sheet Asphalt and Bituminous Concrete Pavements (D 242 - 26 T), as revised	75	0	19
Testing Emulsified Asphalts (D 244 - 36 T), as revised	71	3	20
Spec. for Emulsified Asphalt (for Coarse Aggregate Plant Mixes) (D 397 - 36 T), as revised	65	3	26
Spec. for Emulsified Asphalt (for Retread and Coarse Aggregate Mixes) (D 398 - 36 T), as revised	65	3	26
Spec. for Emulsified Asphalt (Heavy Premix - Summer Grade) (D 399 - 36 T), as revised	65	3	26
Recommended Practice for Bituminous Paving Plant Inspection (D 290 - 28 T), as revised	70	1	23
III. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD			
Test for Ductility of Bituminous Materials (D 113 - 35)	82	0	12
Spec. for Block for Granite Block Pavements (D 59 - 26)	47	0	44
Spec. for Block for Recut Granite Block Pavements (D 131 - 23)	46	0	45
Spec. for Block for Durax Granite Pavements (D 132 - 23)	46	0	45
IV. REVERSION OF STANDARDS TO TENTATIVE			
Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials, Including Some Material Survey Methods (D 75 - 22)	78	0	16
Sampling Bituminous Materials (D 140 - 25)	81	0	13
Test for Loss on Heating of Oil and Asphaltic Compounds (D 6 - 33)	77	0	17
V. WITHDRAWAL OF TENTATIVE STANDARDS			
Spec. for Asphalt Cement, 10 to 15 Penetration, for the Manufacture of Asphalt Block (D 133 - 23 T)	71	3	20
Spec. for Asphalt Cement, 15 to 25 Penetration, for the Manufacture of Asphalt Block (D 134 - 23 T)	71	3	20
Spec. for Asphalt Cement, 25 to 30 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements (D 163 - 23 T)	73	3	18
Spec. for Asphalt Cement, 30 to 40 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements (D 164 - 23 T)	73	3	18
Spec. for Asphalt Cement, 40 to 50 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements and as Filler for Brick and Block Pavements (D 99 - 26 T)	73	3	18
Spec. for Asphalt Cement, 50 to 60 Penetration, for Use in Sheet Asphalt and Asphaltic-Concrete Pavements and as Filler for Block Pavements (D 100 - 26 T)	74	3	17
Spec. for Asphalt Cement, 60 to 70 Penetration, for Use in Sheet Asphalt, Asphaltic Concrete and Asphalt-Macadam Pavements and as Filler for Block Pavements (D 101 - 26 T)	74	3	17
Spec. for Asphalt Cement, 85 to 100 Penetration, for Use in Asphalt-Macadam Pavements (D 102 - 24 T)	73	3	18
Spec. for Asphalt Cement, 100 to 120 Penetration, for Use in Asphalt-Macadam Pavements (D 103 - 24 T)	73	3	18
Spec. for Asphalt Cement, 120 to 150 Penetration, for Use in Asphalt-Macadam Pavements (D 135 - 23 T)	73	3	18

ment box, deep pattern, fulfills these requirements.

to read as follows:

NOTE.—Containers, known in the drug trade as "ointment boxes," meet the above requirements.

Standard Method of Test for Distillation of Bituminous Materials Suitable for Road Treatment (D 20 - 30):[29]

Title.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

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[29] 1936 Book of A.S.T.M. Standards, Part II, p. 1053.

Standard Method of Test for Distillation of [Bituminous Materials] *Tar Products* Suitable for Road Treatment.

Standard Method of Test for Softening Point of Bituminous Materials (Ring-and-Ball Method) (D 36 – 26),[30]

Section 3.—Change to read as follows by the addition of the italicized material:

After cooling *1 hr.* excess material shall be cut off cleanly with a slightly heated knife.

Standard Method of Test for Separation of Liquid Asphaltic Products (D 402 – 36):[31]

Title.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

Standard Method of Test for [Separation of Liquid] *Distillation of Cut-Back* Asphaltic Products.

Standard Specifications for:

Materials for Cement Mortar Bed for Brick, Stone Block, Wood Block, Asphalt and Other Block Pavements (D 57 – 20),

Coal-Tar Pitch for Stone Block Filler (D 112 – 30),

Gravel for Bituminous Concrete Base (D 309 – 30), and

Sand for Sheet Asphalt and Bituminous Concrete Pavements (D 162 – 29):[32]

Section 2.—In the last line of the table of grading requirements, change the screen designation from "$\frac{1}{4}$-in. screen" to read "No. 4 sieve."

Section 4.—Change from its present form, to read as follows:

4. *Mechanical Analysis.*—The test for mechanical analysis shall be made on samples of dried sand, weighing not less than 100 g., following the procedure described in Section 5 of the Tentative Method of Test for Sieve Analysis of Fine and Coarse Aggregate (A.S.T.M. Designation: C 136) of the American Society for Testing Materials. Determination of percentage of particles passing a No. 200 (74-micron) sieve shall be made by dry sieving.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 117 members, with the results shown in Table I.

This report has been submitted to letter ballot of the committee which consists of 117 members; 94 members returned their ballots, of whom 84 have voted affirmatively and 2 negatively.

Respectfully submitted on behalf of the committee,

E. F. KELLEY,
Chairman

PRÉVOST HUBBARD,
Secretary

EDITORIAL NOTE

Subsequent to the annual meeting Committee D-4 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Standards:

Specifications for Expansion Joint Fillers for Concrete (D 544 – 39 T),

Methods of Testing Expansion Joint Fillers for Concrete (D 545 – 39 T), and

Method of Test for Sieve Analysis of Mineral Filler (D 546 – 39 T).

Proposed Revision of Tentative:

Specifications for Asphalt Filler for Brick Pavements (D 241 – 26 T),

Method for Loss on Heating of Oil and Asphaltic Compounds (D 6 – 39 T).

These recommendations were accepted by Committee E-10 on August 24, 1939, the new tentative standards assigned the A.S.T.M. serial designations indicated above, and the new and revised tentative standards appear in the 1939 Book of A.S.T.M. Standards, Part II.

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[30] 1936 Book of A.S.T.M. Standards, Part II, p. 1098.
[31] *Ibid.*, p. 1065.
[32] *Ibid.*, p. 1021.

REPORT ON COOPERATIVE TESTS FOR SIEVE ANALYSIS OF MINERAL FILLERS

Sponsored by Subcommittee B-9 on Size of Aggregates

At the meeting of Subcommittee B-9 on November 1, 1938, it was decided to conduct a series of tests to determine reasonable figures for insertion in the section on reproducibility of results included in the proposed Tentative Method of Test for Sieve Analysis of Mineral Fillers.[1] Samples of four mineral fillers were sent to a number of laboratories with the request that three tests as specified in the proposed method be made on each sample. The samples included two limestone dusts, one portland cement, and one trap rock dust.

Reports were received from twelve laboratories. Laboratory No. 2 reported results obtained by two operators, each of whom made one test with each of three No. 200 sieves and the results for each operator have been considered separately in the study of the data. The observed test values for the No. 200 and No. 80 sieves are given in Table I. No laboratory reported more than a trace retained on the No. 30 sieve, and the data for this sieve are omitted from this discussion.

Average values for the amount passing the No. 200 sieve for each sample are shown in Table II. In the proposed method, no reference to the use of a correction factor for the No. 200 sieve appears, and it was decided to show both the average observed value and the average value with sieve correction where such is available. All except two laboratories show a correction value for the No. 200 sieve. Average values for the No. 80 sieve are given in Table III.

Such data as are available regarding

TABLE I.—SIEVE ANALYSES OF MINERAL FILLERS.

Percentages Passing Each Sieve; Individual Results.

Laboratory	Sample	No. 200 Sieve				No. 80 Sieve			
		1	2	3	Spread	1	2	3	Spread
No. 1	A	95.5	95.4	95.2	0.3	99.6	99.6	99.6	0.0
	B	73.1	72.5	72.2	0.9	99.4	99.4	99.4	0.0
	C	85.3	85.2	85.4	0.2	99.2	99.2	99.2	0.0
	D	92.0	92.3	92.0	0.3	99.6	99.6	99.6	0.0
No. 2A	A	96.0	96.2	96.5	0.5	99.8	99.8	99.8	0.0
	B	74.0	73.8	74.0	0.2	99.0	99.0	99.0	0.0
	C	86.8	86.8	87.2	0.4	99.2	99.2	99.2	0.0
	D	93.1	93.1	93.1	0.0	99.4	99.4	99.4	0.0
No. 2B	A	95.2	95.7	95.1	0.6	99.8	99.8	99.8	0.0
	B	72.7	72.9	72.6	0.3	99.5	99.5	99.5	0.0
	C	85.6	85.9	85.2	0.7	99.3	99.3	99.3	0.0
	D	92.7	92.7	92.1	0.6	99.9	99.9	99.9	0.0
No. 3	A	95.5	95.6	95.4	0.2	99.7	99.7	99.7	0.0
	B	71.6	72.3	72.3	0.7	99.5	99.5	99.5	0.0
	C	85.9	85.7	86.0	0.3	99.2	99.2	99.2	0.0
	D	92.6	92.5	92.2	0.4	99.6	99.6	99.6	0.0
No. 4	A	95.5	95.1	95.4	0.4	99.8	99.5	99.6	0.3
	B	73.7	73.1	73.0	0.7	99.1	99.2	99.2	0.1
	C	85.6	85.9	86.0	0.4	99.1	99.1	99.1	0.0
	D	91.8	91.9	91.9	0.1	99.5	99.5	99.6	0.1
No. 5	A	95.3	95.2	95.4	0.2	99.5	99.6	99.6	0.1
	B	73.1	73.1	73.0	0.1	99.4	99.4	99.4	0.0
	C	85.5	85.5	85.4	0.1	99.1	99.1	99.1	0.0
	D	92.3	92.5	92.6	0.3	99.6	99.5	99.6	0.1
No. 6	A	96.0	95.1	95.2	0.9	99.8	99.6	99.4	0.4
	B	74.0	74.6	73.4	1.2	98.9	99.1	99.1	0.2
	C	87.4	87.2	87.5	0.3	98.3	98.1	98.5	0.4
	D	93.4	93.6	93.2	0.4	99.5	99.4	99.4	0.1
No. 7	A	96.5	96.5	96.5	0.0	99.5	99.5	99.5	0.0
	B	75.5	75.5	75.5	0.0	99.5	99.5	99.5	0.0
	C	89.0	88.5	88.5	0.5	99.0	99.5	99.5	0.5
	D	93.5	94.0	93.5	0.5	99.5	99.5	99.5	0.0
No. 8	A	96.0	96.0	96.0	0.0	99.5	99.5	99.5	0.0
	B	75.5	74.0	74.0	1.5	99.5	99.5	99.5	0.0
	C	87.0	87.0	87.0	0.0	99.0	99.0	99.0	0.0
	D	92.5	93.0	92.5	0.5	99.5	99.5	99.5	0.0
No. 9	A	95.6	95.4	95.4	0.2	99.6	99.6	99.6	0.0
	B	72.2	71.8	73.0	1.2	99.2	99.2	99.2	0.0
	C	85.4	85.2	85.2	0.2	99.0	99.0	99.0	0.0
	D	92.4	92.4	92.6	0.2	99.6	99.6	99.6	0.0
No. 10	A	96.2	96.3	96.2	0.1	99.7	99.6	99.7	0.1
	B	74.0	74.0	74.0	0.0	99.4	99.4	99.4	0.0
	C	87.1	87.8	88.0	0.9	99.2	99.2	99.2	0.0
	D	93.1	93.1	92.7	0.4	99.6	99.6	99.5	0.1
No. 11	A	95.1	95.1	95.1	0.0	99.5	99.6	99.6	0.1
	B	71.9	72.7	72.8	0.9	98.9	98.8	98.9	0.1
	C	85.7	85.3	85.1	0.6	98.9	98.9	98.9	0.0
	D	92.0	91.9	91.9	0.1	99.4	99.4	99.3	0.1
No. 12	A	96.0	95.8	95.9	0.2	99.7	99.6	99.6	0.1
	B	74.0	73.9	74.3	0.4	99.3	99.4	99.3	0.1
	C	87.4	87.7	87.5	0.3	99.2	99.2	99.2	0.0
	D	93.5	93.6	93.6	0.1	100.0	99.6	99.6	0.4

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[1] See Editorial Note, p. 428.

sieve constants for the sieves used are given in Table IV. All sieves were reported to be in good condition.

TABLE II.—SIEVE ANALYSES OF MINERAL FILLERS.

Average Results.

Laboratory	Observed Percentage Passing No. 200 Sieve				Corrected Percentage Passing No. 200 Sieve			
	A	B	C	D	A	B	C	D
No. 1	95.4	72.6	85.3	92.1	....	....	....	....
No. 2A	96.2	73.9	86.9	93.1	97.5	75.2	88.2	94.4
No. 2B	95.3	72.7	85.6	92.5	97.8	75.2	88.0	95.0
No. 3	95.5	72.1	85.9	92.4	97.3	73.9	87.7	94.2
No. 4	95.3	73.3	85.8	91.9	98.0	76.0	88.5	94.6
No. 5	95.3	73.1	85.5	92.5	95.9	73.7	86.1	93.1
No. 6	95.4	74.0	87.4	93.4	....	....	....	....
No. 7	96.5	75.5	88.5	93.5	95.8	74.8	88.0	93.0
No. 8	96.0	74.5	87.0	92.5	96.0	74.5	87.0	92.5
No. 9	95.5	72.3	85.3	92.5	97.0	73.8	86.8	94.0
No. 10	96.2	74.0	87.6	93.0	95.5	73.3	86.9	92.3
No. 11	95.1	72.5	85.4	91.9	95.5	74.8	86.6	92.6
No. 12	95.9	74.1	87.5	93.6	95.9	74.1	87.5	93.6
Average	95.7	73.4	86.4	92.7	96.6	74.5	87.4	93.6
Maximum	96.5	75.5	88.5	93.6	98.0	76.0	88.5	95.0
Minimum	95.1	72.1	85.3	91.9	95.5	73.3	86.1	92.3
Spread	1.4	3.4	3.2	1.7	2.5	2.7	2.4	2.7

TABLE III.—SIEVE ANALYSES OF MINERAL FILLERS.

Average Results.

Laboratory	Percentage Passing No. 80 Sieve			
	A	B	C	D
No. 1	99.6	99.4	99.2	99.6
No. 2A	99.8	99.0	99.2	99.4
No. 2B	99.8	99.5	99.3	99.9
No. 3	99.7	99.5	99.2	99.6
No. 4	99.6	99.2	99.1	99.5
No. 5	99.6	99.4	99.1	99.6
No. 6	99.6	99.0	98.3	99.4
No. 7	99.5	99.5	99.5	99.5
No. 8	99.5	99.5	99.0	99.5
No. 9	99.6	99.2	99.0	99.6
No. 10	99.7	99.4	99.2	99.6
No. 11	99.6	98.9	98.9	99.4
No. 12	99.6	99.3	99.2	99.7
Average	99.6	99.3	99.1	99.6
Maximum	99.8	99.5	99.5	99.9
Minimum	99.5	98.9	98.3	99.4
Spread	0.3	0.6	1.2	0.5

TABLE IV.—SIEVES USED IN TESTS.

Laboratory	No. 200 Sieve				No. 80 Sieve		No. 30 Sieve	
	Maker	Opening, in.	Corr. Factor	Standard Sample	Maker	Opening, in.	Maker	Opening, in.
No. 1	Tyler	0.0029	....	....	Tyler	0.0069	Tyler	0.0232
No. 2	Tyler	0.0029	−1.5	46r	Tyler	0.0069	Tyler	0.0232
	Tyler	0.0029	−1.3	46r	....	....	....	....
	Tyler	0.0029	−1.1	46r	....	....	....	....
	Tyler	0.0029	−2.3	46r	....	....	....	....
	Tyler	0.0029	−2.2	46r	....	....	....	....
	Tyler	0.0029	−2.9	46r	....	....	....	....
No. 3	Tyler	0.0029	−1.8	46r	Tyler	0.0069	Tyler	0.0232
No. 4	Tyler	0.0029	−2.7	46r	Tyler	0.0069	Tyler	0.0232
No. 5	Tyler	0.0029	−0.6	47g	Tyler	0.0069	Tyler	0.0232
No. 6	Tyler	0.0029	....	....	Newark	0.0070	Tyler	0.0232
No. 7	Tyler	0.0029	+0.7	....	Tyler	0.0069	Tyler	0.0232
No. 8	H. & M.	....	−0.1	46q	H. & M.	....	H. & M.	....
No. 9	Tyler	0.0029	−1.5	46r	Tyler	0.0069	Tyler	0.0232
No. 10	Humboldt	0.0029	+0.7	46q	Humboldt	0.0070	Precision	0.0232
No. 11	Tyler	0.0029	91.3[a]	....	Newark	0.0070	Newark	0.0232
No. 12	Newark	0.0029	+0.06	46p	....	....	....	....

[a] A percentage of the amount retained on the sieve.

The proposed method states that the percentage passing each sieve shall be reported to the nearest 0.5 per cent. If the values shown in Table II are so expressed, the ranges in values as shown in Table V are found. Some values marked extreme minimum or maximum have been omitted from consideration of the nominal range on the assumption that these are in error since they differ so greatly from the average in comparison with the other values. A maximum range of 2.0 per cent is found for the uncorrected values and of 2.5 per cent for the values with sieve corrections. It is apparent that in some instances either the sieving ability of the sieve has changed since the sieve correction was obtained, or the sieve correction is in error since the corrected values show a wider spread than those without correction.

From the results obtained it appears that a reasonable value for agreement between different laboratories is 2.0 per cent for the No. 200 sieve. The reported values for the No. 80 sieve show a much better agreement. Reference to Table I shows that in relatively few cases is the spread between the results of three tests made by a given operator greater than 1.0 per cent, and it is believed that this value is reasonable for inclusion in the test method.

TABLE V.—SIEVE ANALYSES OF MINERAL FILLERS.

Range in Test Values for No. 200 Sieve.

Sample	Condition	Extreme Minimum (omitted)	Minimum	Maximum	Extreme Maximum (omitted)	Range
A........	No correction	.....	95.0	96.5	.....	1.5
B........	No correction	72.0	72.5	74.5	75.5	2.0
C........	No correction	.....	85.5	87.5	88.5	2.0
D........	No correction	.....	92.0	93.5	.....	1.5
A........	Corrected	.....	95.5	98.0	.....	2.5
B........	Corrected	.....	73.5	75.0	76.0	1.5
C........	Corrected	86.0	86.5	88.5	.....	2.0
D........	Corrected	.....	92.5	95.0	.....	2.5

Respectfully submitted on behalf of the subcommittee,

E. F. KELLEY,
Chairman.

REPORT OF COMMITTEE D-5

ON

COAL AND COKE

Committee D-5 on Coal and Coke held two meetings in the past year: in Chicago, Ill., on October 12, 1938, and in Columbus, Ohio, on March 7, 1939; a third meeting will be held at the annual meeting of the Society in June, 1939, in Atlantic City, N. J.

H. F. Hebley of the Commercial Testing and Engineering Co. has been appointed chairman of Subcommittee XIII on Coal Sampling, succeeding J. B. Morrow, who resigned the chairmanship but who will continue to serve on the subcommittee. C. A. Lunn has succeeded W. F. Davidson, resigned, as the representative of the Consolidated Edison Co. of New York, Inc.; and A. R. Mumford has replaced W. F. Davidson as the representative of the Edison Electric Institute. The personal membership of W. D. Langtry has been transferred to a company membership of the Commercial Testing and Engineering Co. with Messrs. Langtry and Hebley as joint representatives. The Sloss-Sheffield Steel and Iron Co., represented by W. O. McMahon, has been added to the membership. B. P. Mulcahy of the Citizens Gas and Coke Utility Co. has been transferred from a consulting member to a committee member. The Reading Iron Co., which was represented by C. T. Ressler, has resigned from the committee.

The membership of the committee now totals 44, of whom 13 are classified as consumers, 12 as producers, and 19 as general interest members. In addition, the committee has 17 consulting members.

No recommendations affecting standards are proposed by the committee at this time, but Subcommittee XIV on Dustiness of Coal and Coke has completed a new Method of Test for Index of Dustiness of Coal and Coke. This method which is appended hereto[1] as information will after approval by the committee be presented to the Society during the summer through Committee E-10 on Standards for publication as tentative.

The committee has reviewed the following standards under its jurisdiction which have not been revised within the past six years or longer and considers them to be in accord with present practice. With the exception of general editorial changes comprising improvements in form and arrangement, the standards will be continued without revision:

Standard Specifications for:
- Gas and Coking Coals (D 166 – 24),

Standard Methods of Test for:
- Shatter Test for Coke (D 141 – 23) (A.S.A. K20.4 – 1936),
- Volume of Cell Space of Lump Coke (D 167 – 24) (A.S.A. K20.5 – 1936),
- Fineness of Powdered Coal (D 197 – 30),
- Cubic Foot Weight of Crushed Bituminous Coal (D 291 – 29) (A.S.A. K20.1 – 1936),
- Cubic Foot Weight of Coke (D 292 – 29) (A.S.A. K20.2 – 1936),
- Sieve Analysis of Coke (D 293 – 29),

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[1] See Editorial Note, p. 435.

Tumbler Test for Coke (D 294 - 29) (A.S.A. K20.3—1936),
Sieve Analysis of Crushed Bituminous Coal (D 311 - 30), and
Standard Definitions of Terms Relating to Coal and Coke (D 121 - 30).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Methods of Testing (W. A. Selvig, chairman).—Last year the subcommittee recommended a tentative revision of the procedure for determining the fusibility of coal ash, as described in the Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 37) (A.S.A. K 18 - 1937), which was accepted by the Society for publication. In view of the importance of the ash fusion test the subcommittee is not recommending that the revision be adopted as standard this year; continuance as tentative for another year is desirable to afford further opportunity for criticism.

Subcommittee II on Nomenclature and Definitions (H. C. Porter, chairman).—The subcommittee is continuing in its present status the Tentative Definition of the Term Coke (D 121-30 T) pending further consideration by Committee E-8 on Nomenclature and Definitions. The Tentative Definitions of the Terms Gross Calorific Value and Net Calorific Value of Fuels (D 407-35 T) are also being continued as tentative.

Subcommittee VII on Pulverizing Characteristics of Coal (John Van Brunt, chairman).—This subcommittee is continuing as tentative, to afford further trial, the two methods of testing grindability of coal, namely, the Tentative Method of Test for Grindability of Coal by the Ball-Mill Method (D 408 - 37 T), and the Tentative Method of Test for Grindability of Coal by the Hardgrove-Machine Method (D 409 - 37 T). Considerable data are being accumulated as a result of the use of these two methods.

During the year the following publications on grindability values of various coals appeared:

"Grindability of Coals Mined in the United States, Canada, and Other Countries," The Babcock & Wilcox Co., New York City, 34 pp. (1938).

E. S. Hertzog and J. R. Cudworth "Grindability of Alabama Coals," *Report of Investigations 3382*, U. S. Bureau of Mines, 8 pp. (1938).

H. F. Yancey and M. R. Geer, "Ball-Mill Grindability Indexes of Some American Coals," *Report of Investigations 3409*, U. S. Bureau of Mines, 9 pp. (1938).

Subcommittee VIII on Foundry Coke Specifications (J. T. MacKenzie, chairman).—This subcommittee has under consideration a revision of the Standard Specifications for Foundry Coke (D 17 - 16) based on tolerances for the variation of analyses which may be permitted from analytical values stated in any given purchase specifications.

Subcommittee XI on Coal Friability (R. E. Gilmore, chairman).—In 1937 the subcommittee recommended two tentative methods of testing coal friability: namely, the Tentative Method of Drop Shatter Test for Coal (D 440 - 37 T), and the Tentative Method of Tumbler Test for Coal (D 441 - 37 T). Both of these methods are being used as routine tests at the Fuel Research Laboratories, Canada Bureau of Mines. Studies are being made at these laboratories to determine the relationships between testing 2 by 3-in. lump coal by the drop shatter test method and the observed handling properties of the coals. Results of these studies will be published by the Canada Bureau of Mines. An investigation of friability of Alabama coals, using the tumbler test method, has been published by the U. S. Bureau of Mines.[2]

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[2] E. S. Hertzog and J. R. Cudworth, "Friability of Alabama Coals," *Report of Investigations 3384*, U. S. Bureau of Mines (1938).

Subcommittee XIII on Coal Sampling (H. F. Hebley, chairman).—The subcommittee held a meeting in Chicago Ill., on October 12, 1938, and a meeting in New York City on February 15, 1939. The Tentative Method of Sampling Coals Classed According to Ash Content (D 492 - 38 T), accepted for publication last year, is to remain as tentative pending sampling experiments being conducted to check the accuracy of the method when applied to coals of varying ash content. Also, the subcommittee is formulating methods for sampling the larger sizes of coal and run-of-mine coal.

Dr. E. S. Grumell of Imperial Chemical Industries, Ltd., the eminent British authority on coal sampling, attended the subcommittee meeting held in New York City in February. The work of Doctor Grumell and his associates in applying the theory of errors to coal sampling problems has been very helpful in standardizing coal sampling methods, and the subcommittee is grateful to him for his interest and assistance in its work.

Subcommittee XIV on Dustiness of Coal and Coke (O. O. Malleis, chairman). —As mentioned earlier in this report, the subcommittee has prepared a Proposed Method of Test for Index of Dustiness of Coal and Coke. The method is a measure of the relative index of the dust produced when coal or coke is handled. It should be of value in determining the effectiveness of various methods in use for dust-proofing coal or coke by means of chemicals or oil sprays.

The method is essentially that described by Powell and Russell[3] and later used by Pilcher and Sherman[4] for studying the effectiveness of dust-proofing coal with oil and other petroleum products.

Subcommittee XV on Plasticity and Swelling of Coal (C. C. Russell, chairman).—This subcommittee held a meeting on October 12, 1938, in Chicago, Ill. A series of seven coking coals ranging in rank from low volatile Pocahontas coal to high volatile Illinois coal have been tested for expansion properties during carbonization by various methods. Ten laboratories made these cooperative tests and nine methods were used. These same coals also were tested by five different methods for agglutinating values and for plastic properties during carbonization. The data from these cooperative tests have been compiled for study by the subcommittee with a view to evaluating available methods for testing expansion characteristics of coals in coke ovens and their general plastic properties during carbonization.

Subcommittee XVI on Ignitibility of Coal and Coke (R. A. Sherman, chairman).—The subcommittee held a meeting in Chicago, Ill., on October 12, 1938. As a part of its work in developing a method of test, the subcommittee has reached agreement on a proposed definition of the term ignitibility, as follows:

Ignitibility.—The ignitibility of a fuel is that characteristic which determines the ease with which the fuel may be brought to a condition of self-supporting, active oxidation. The ignitibility is governed not only by the inherent chemical characteristics of the fuel that determine its rate of oxidation at various temperatures but also by the physical characteristics of the fuel and its surroundings that determine the rate at which it can be heated. Among these physical characteristics are (*1*) the size of the pieces of fuel, (*2*) the specific heat of the fuel, (*3*) the thermal conductivity of the pieces and the aggregate, (*4*) the rate at which the oxygen or air is brought into contact with the fuel, and (*5*) the rate of heat loss to the surroundings. Chemical and physical changes, such as melting and decomposition of bituminous coal, may occur as the fuel is heated.

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[3] A. R. Powell and C. C. Russell, "Method for Determining the Dustiness of Coal and Coke," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 5, p. 340 (1933).

[4] J. M. Pilcher and R. A. Sherman, "The Treatment of Coal with Oil and Other Petroleum Products," *Technical Paper 113*, Am. Inst. Mining and Metallurgical Engrs. June, 1939.

This report has been submitted to letter ballot of the committee which consists of 44 members; 42 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. C. FIELDNER,
Chairman.

W. A. SELVIG,
Secretary.

EDITORIAL NOTE

Subsequent to the annual meeting Committee D-5 presented to the Society through Committee E-10 on Standards a proposed Tentative Method of Test for Index of Dustiness of Coal and Coke. This new tentative method was accepted by Committee E-10 on August 24, 1939, and appears in the 1939 Book of A.S.T.M. Standards, Part III, bearing the designation D 547 – 39 T.

REPORT OF SECTIONAL COMMITTEE
ON
CLASSIFICATION OF COALS

A.S.A. PROJECT: M20

The Sectional Committee on Classification of Coals, functioning under the procedure of the American Standards Association, held one meeting in the past year, in New York City, on February 15, 1939.

The committee approved the appointments of E. E. Ramey, as representative of the Railway Fuel and Traveling Engineers' Association, *vice* Malcolm Macfarlane, deceased, and of H. L. Littell with H. G. Turner, alternate, as representatives of the Anthracite Institute, *vice* E. W. Parker and L. W. Hildreth, resigned. The resignation of W. R. Roberts, representing the American Mining Congress, was accepted and the advancement of G. B. Southward, alternate, to succeed Mr. Roberts was approved.

The presentation of this report with the recommendations affecting standards contained herein marks the completion of the work assigned to the Sectional Committee on Classification of Coals. The committee was organized in 1927 with the following scope:

> The classification of all coals from anthracite to lignite, to be based upon such chemical and physical characteristics as will make the plan most readily adaptable to industrial and commercial use on a national scale.

A comprehensive program of fact finding and research was undertaken by the committee in cooperation with the Associate Committee on Coal Classification and Analysis of the National Research Council of Canada. Previously proposed systems of classification were critically examined and their application to the wide variety of North American coals was carefully studied. Voluminous data on the chemical and physical properties of coals were collected, and much research was sponsored by the committee in this connection and in the development of standard methods for assessing certain properties of coal, such as weathering and agglomeration, that seemed important in its classification.

From these studies the committee recognized that coals could be usefully classified, according to their inherent composition and properties, along three different lines, as follows:

1. By rank, that is, according to the degree of metamorphism, or progressive alteration in the natural series from lignite to anthracite;
2. By grade, that is, according to the nature and amount of impurities present, screen size, etc.; and
3. By type, that is, by varieties such as common banded, splint, cannel, and boghead or algal coals.

Tentative Specifications for Classification of Coals by Rank (D 388) and by Grade (D 389) were formulated by the committee and accepted by the A.S.T.M.

for publication as tentative in 1934. In 1937 the rank and grade classifications were adopted by the Society and were approved as American standards by the American Standards Association; an amendment to the rank classification was adopted in 1938. The acceptance for publication in 1938 of Tentative Definitions for Varieties of Bituminous and Subbituminous Coals (D 493 – 38 T) completed the development of the classification of coals along the three lines of rank, grade, and variety (in place of type). The final recommendations of the committee are given below.

ADOPTION OF TENTATIVE STANDARD AS STANDARD

The committee recommends that the Tentative Definitions for Varieties of Bituminous and Subbituminous Coals (D 493 – 38 T)[1] be approved for reference to letter ballot of the Society for adoption as standard. The committee further recommends that these definitions be submitted to the American Standards Association for approval as American standard upon their adoption by the A.S.T.M.

This recommendation has been submitted to letter ballot of the committee which consists of 29 members; 27 members returned their ballots, of whom 24 have voted affirmatively, 0 negatively, and 3 members marked their ballots "not voting."

ACTIVITIES OF TECHNICAL COMMITTEES

The Technical Committee on Nomenclature (E. A. Holbrook, chairman) held no meetings in the past year but it conducted a letter ballot on the adoption of the Tentative Definitions for Varieties of Bituminous and Subbituminous Coals (D 493 – 38 T). The technical committee consists of 11 members; 9 members returned their ballots, all of whom voted affirmatively.

This report has been submitted to letter ballot of the committee which consists of 29 members; 27 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. C. FIELDNER,
Chairman.

J. D. BATTLE,
Secretary.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 915 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 690.

REPORT OF COMMITTEE D-6

ON

PAPER AND PAPER PRODUCTS

Committee D-6 on Paper and Paper Products was organized at a meeting held in New York City on June 28, 1937. Two meetings were held during 1938: one in the spring in Rochester, N. Y., and one during the annual meeting of the Society in June at Atlantic City, N. J. Another meeting was held in New York City on April 3, 1939. At these meetings the organization of the various subcommittees was arranged and the planning of detailed programs of work was completed. The present activities of the various subcommittees are described later in this report.

The following statement of scope of the work of the committee has been adopted:

Scope.—(*a*) The study, review, and adoption of general testing methods for paper and paper products.

(*b*) The study, review, and adoption of definitions of terms and nomenclature relating to paper and paper products and to the testing thereof.

(*c*) The study of use requirements of paper and paper products and the significance of test results.

(*d*) Study of the need for specifications and the preparation of specifications for paper and paper products in those fields for which there is need.

During the year cooperative relations have been arranged between Committee D-6 and Committee D-9 on Electrical Insulating Materials in regard to the interest of the latter committee in electrical insulating papers. In this connection each committee will be represented formally upon the other committee, R. W. Chadbourne to represent Committee D-9, and L. S. Reid to represent Committee D-6.

Committee D-6 has also established effective cooperative relations with the Technical Association of the Pulp and Paper Industry to insure that test methods on the same subjects issued by the A.S.T.M. and T.A.P.P.I. will not differ radically. This cooperation is being carried out through the formation of a Joint A.S.T.M.-T.A.P.P.I. Committee on Paper Testing Methods, composed of two members of Committee D-6 and two members from T.A.P.P.I. The personnel of this committee is as follows: A.S.T.M. representatives: L. S. Reid (chairman), and R. C. Griffin; T.A.P.P.I. representatives: B. L. Wehmhoff and P. F. Wehmer.

The present membership of Committee D-6 is 46, of whom 17 are classified as producers, 14 as consumers, and 15 as general interest members.

NEW TENTATIVE STANDARDS

The committee recommends that the following two methods of test be accepted for publication as tentative:

Tentative Method of Test for Bulking Thickness of Paper,[1] and

Tentative Method of Test for Machine Direction of Paper.[1]

These proposed tentative methods

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[1] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

which are based upon the Standard Methods T426m and T409m of the Technical Association of the Pulp and Paper Industry have been submitted to letter ballot of the committee which consists of 46 voting members, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Item	Affirmative	Negative	Ballots Marked "Not Voting"
New Tentative Standards			
Test for Bulking Thickness of Paper	25	0	3
Test for Machine Direction of Paper	30	0	1

Activities of Subcommittees

Subcommittee I on Paper Testing Methods (W. E. Emley, chairman) has been working on a critical study of various methods of test which have been approved by T.A.P.P.I. In this study a T.A.P.P.I. method is assigned to a member of the subcommittee for review and report. The following methods are in this manner now being given consideration:

T.A.P.P.I. Standard	Subject
T 410m	Basis Weight
T 412m	Moisture
T 414m	Tearing Strength
T 427m	Saturating Properties
T 433m	Water Resistance

When an individual member has completed his review his recommendations are transmitted to the other members of the subcommittee for their consideration. At present Method T404m on Tensile Strength has this status. When all members of the subcommittee have had an opportunity to study the recommendations, and the method has been revised in accordance with the criticisms received, the revised method is then referred to letter ballot of the subcommittee. The following methods are now being balloted upon:

T403m on Bursting Strength.
T411m on Thickness,
T413m on Ash, and
T415m on Casein.

The methods listed below have been approved by the subcommittee and are now receiving consideration in the Joint A.S.T.M.-T.A.P.P.I. Committee:

T400m on Sampling, and
T425m on Opacity.

Subcommittee II on Significance of Test Methods (C. C. Heritage, chairman) is preparing a monograph covering the significance of tests and the definition of terms, nomenclature, and properties of paper, in which the interested committees of A.S.T.M. and T.A.P.P.I. are to be invited to cooperate. The subcommittee is being assisted in this activity by Subcommittee III on Paper Bags (R. M. Bates, chairman).

Subcommittee IV on Fiberboard and Fiberboard Containers (D. L. Quinn, chairman) has launched an extensive research-testing program, with the following objectives:

1. To secure comprehensive and dependable data on the moisture content of container grades of paperboards and of corrugated fiberboard containers resulting from conditioning these products in accordance with several specified procedures.
2. To determine whether moisture content can be eliminated as a variable by any of the conditioning methods proposed as shown by the influence of varying moisture content on certain specified physical properties when these are measured in the manner prescribed.
3. To determine the practicability of each of the methods of conditioning outlined, in relation to duplication of test results.

Work on this program has been actively started and is being carried on at six laboratories which generously offered to cooperate. The subcommittee has held several meetings, the last one being in Columbus, Ohio, on March 6 and 7, 1939.

This report has been submitted to letter ballot of the committee which consists of 46 voting members; 31 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

R. C. GRIFFIN,
Chairman.

L. S. REID,
Secretary.

EDITORIAL NOTE

Subsequent to the annual meeting Committee D-6 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Methods of:

Test for Water-Soluble Acidity or Alkalinity of Paper (D 548 - 39 T), and

Test for Resin in Paper (D 549 - 39 T)

These new tentative methods were accepted by Committee E-10 on August 24, 1939, assigned the A.S.T.M. serial designations indicated above, and appear in the 1939 Book of A.S.T.M. Standards, Part III.

REPORT OF COMMITTEE D-7
ON
TIMBER

Committee D–7 on Timber presents herewith a report of its activities during the past year. The committee has held one formal meeting in Chicago, Ill., on March 14, 1939.

In the 1938 report[1] reference was made to a study of the interpretation of knot measurements, particularly when applied to oak wood. A memorandum prepared by Mr. J. A. Newlin entitled "The Size of a Knot," covering the interpretation of knot definitions as applied particularly to oak knots, is presented as information in an appendix to this report. It is recommended that this appended material be included as an informational section in the Standard Definitions of Terms Relating to Timber (D 9 – 30).

I. Revision of Tentative Standard

The committee recommends that Section 4 of the Tentative Method of Test for Tar Acids in Creosote and Creosote – Coal Tar Solutions (D 453 – 38 T)[2] be revised as indicated below and the method continued as tentative. The method as revised will be identical with the one recently adopted as standard by the American Wood-Preservers' Association.

Section 4.—Change from its present form: namely,

> 4. The amount of tar acids shall be reported as a percentage of the fraction tested, calculated as follows:
>
> $$\text{Percentage of tar acids} = \frac{\text{vol. of tar acids in ml.}}{\text{wt. of fraction in grams}} \times 100$$
>
> In the above formula, the assumption is made that 1 ml. of tar acids weighs 1 g.

to read as follows:

> 4. The result shall be reported as a percentage of the fraction tested, calculated as follows:
>
> Tar acids, per cent
>
> $$= \frac{\text{sp. gr. } 25\text{ C.}/15.5\text{ C.}^{a} \times \text{vol. of tar acids in ml.}}{\text{wt. of fraction in grams}} \times 100$$
>
> ---
>
> [a] For practical purposes the specific gravity of the tar acids may be assumed to be 1.040.

II. Revision of Standard

The Standard Method of Test for Distillation of Creosote (D 246 – 33)[3] has been subject to consideration on the part of this committee as well as the American Wood-Preservers' Association. As a result, a revision of the standard consisting largely of editorial changes, except for the modification in Section 10, is recommended. Since the method is so well established and the proposed changes are of such a minor nature the committee recommends the revisions for immediate adoption, and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society.

Section 9.—Change the third sentence of the first paragraph to read as follows by the addition of the italicized word and the omission of the word in brackets:

> The thermometer shall be inserted through a cork in the [tubulature] ***neck*** with the bottom of the bulb 12 to 13 mm. from the surface of the oil in the retort.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 414 (1938).

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 909 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 692.

[3] 1936 Book of A.S.T.M. Standards, Part II, p. 542.

Change the second paragraph of this section to read as follows by the addition of the italicized words and the omission of the word in brackets:

> The axis of the bulb *of the flask* through the [tubulature] *center of the neck* shall be vertical *and the thermometer shall be aligned on this axis.*

Change the first sentence of the third paragraph to read as follows by the addition of the italicized words and the omission of those in brackets:

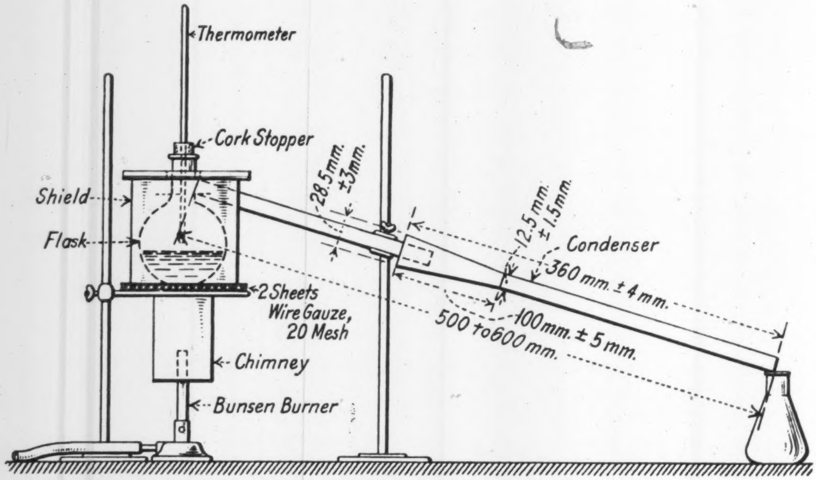

FIG. 1.—Distillation Apparatus Assembly.

> The distance from the [bulb of the thermometer] *neck of the flask* to the outlet end of the condenser tube shall be not more than 600 nor less than 500 mm.

Fig. 3.—Replace the present figure with the accompanying Fig. 1 which has been revised in line with the change being recommended in Section 9, above.

Section 10.—Change the first two sentences to read as follows by the addition of the italicized words and the omission of those in brackets:

> One hundred grams (100 ±0.1 g.) of the sample shall be weighed into the flask, the apparatus assembled and heat applied so that the first drop [comes over] *falls from the end of the condenser* in [from 5 to 15 minutes] *10 min. ± 100 sec.* [The distillation shall be conducted at the rate of between 80 and 120 drops per minute and] *The rate at the end of condenser shall be adjusted to 90 to 100 drops per min. within 2 min. after the first drop and shall be maintained at 80 to 100 drops per min. throughout the distillation.* The distillate *shall be* collected in weighed receivers.

III. ADOPTION OF TENTATIVE STANDARD AS STANDARD

The committee recommends that the Tentative Specifications for Zinc Chloride (D 432 – 36 T)[4] be approved for reference to letter ballot of the Society for adoption as standard. These specifications have stood for three years and no criticism or suggestions for improvement have been received.

IV. REVISION CONTINUED AS TENTATIVE

The definition of water-gas tar has been published since 1933 as a tentative revision of the Standard Definitions of Terms Relating to Timber Preservatives (D 324 – 33). No action has been taken this year by Committee E-8 on Nomenclature and Definitions with respect to this proposed definition and Committee D-7 accordingly recommends that the definition for water-gas tar be continued as tentative pending further study.

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 847 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 691.

V. STANDARDS CONTINUED WITHOUT REVISION

In order to ascertain whether they are still in accord with present practice the committee has reviewed the following standards which have been published for a period of six years or longer without revision, and recommends that they be continued as standard without change:

Standard Methods of:

Sampling and Testing of Creosote (D 38 – 33).

Test for Coke Residue of Creosote (D 168 – 30).

Test for Insoluble Matter in Creosote (D 367 – 33). It is probable that in a year or so certain changes in this method will be recommended which are now being discussed with the American Railway Engineering Association and the American Wood-Preservers' Association.

Test for Specific Gravity of Creosote (D 368 – 33).

Test for Specific Gravity, 38 C./15.5 C., of Creosote Fractions (D 369 – 33).

Volume and Specific Gravity Correction Tables for Creosote and Coal Tar (D 347 – 33).

Chemical Analysis of Zinc Chloride (D 199 – 27).

Test for Water in Creosote (D 370 – 33).

Testing Small Clear Specimens of Timber (D 143 – 27; ASA 04a – 1927). There will probably be some minor revisions in this method presented in another year.

Conducting Static Tests of Timbers in Structural Sizes (D 198 – 27; ASA 04b – 1927).

Standard Specifications for Wooden Paving Blocks for Exposed Pavements (D 52 – 20). While these specifications are no longer in active use the committee decided that it would be advisable to retain them pending decisions on the part of the industries involved as to the necessity of either abandoning the present standard or developing new specifications.

Standard Definitions of Terms Relating to Timber (D 9 – 30). These terms are being considered for revision; this has been delayed awaiting further action by the Central Committee on Lumber Standards and the National Bureau of Standards which are cooperating in developing a revision of the American Lumber Standards.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 24 members; 23 members returned their ballots, the results being shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF TENTATIVE STANDARD			
Test for Tar Acids in Creosote and Creosote - Coal-Tar Solutions (D 453 - 38 T)	17	0	6
II. REVISION OF STANDARD			
Test for Distillation of Creosote (D 246 - 33), immediate adoption	18	0	5
III. ADOPTION OF TENTATIVE STANDARD AS STANDARD			
Specifications for Zinc Chloride (D 432 - 36 T)	18	0	5

This report has been submitted to letter ballot of the committee which consists of 24 members; 23 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

HERMANN VON SCHRENK,
Chairman.

JOHN A. NEWLIN,
Secretary.

APPENDIX

THE SIZE OF A KNOT

(Supplementing Definition of a Knot)

By John A. Newlin[1]

The A.S.T.M. standards for timber give very definite knot sizes that are to be permitted in any given grade and size of timber and a very concise and accurate definition of a knot. But it is not always easy to trace the outline of the knot on the surface of a timber and segregate the knot from the cross grain around the knot, which is a part of the body of the tree.

Sometimes there is a difference in color between the end grain of the limb wood and the surrounding wood. Sometimes there is a marked change in color that merely marks the heartwood of a live knot, and the sapwood of the knot may have the same color as the surrounding wood.

Again, we find knots in which there is practically no difference in color. The body of the tree is usually enlarged at a knot so that, when a knot is sawed through, the ring growth of the body wood looks very much like a part of the knot. How then are knot sizes to be determined?

There are two ways of determining the limits of a live knot when color or general appearance does not clearly demonstrate the boundary of the knot:

First.—The rings on the top of a limb are usually narrower than those on the bottom; and on a tangentially cut surface these rings at the top are narrower than those showing immediately above the knot in the body of the tree; also the rings in the body of the tree get wider as you measure away from the knot. The growth ring at the top of the knot can be traced around the knot to outline

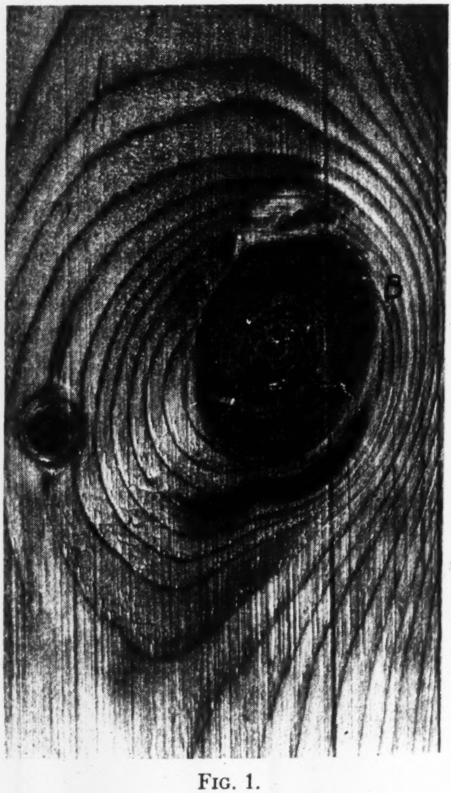

Fig. 1.

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[1] Specialist in the Mechanics of Wood, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, maintained at Madison, Wis., in cooperation with the University of Wisconsin.

the size of the knot. When the knot is cut at an angle there will, as a rule, still be a place to one side of the top where the relatively narrow ring growth of the knot is suddenly changed to the wider growth rings of the tree trunk (see A, Fig. 1). On the side of the knot opposite these narrow growth rings, the growth rings will usually be found to get wider all the way from the pith center out and it is often very difficult to establish the limit of the knots on that side except by tracing the growth rings from the other side of the knot.

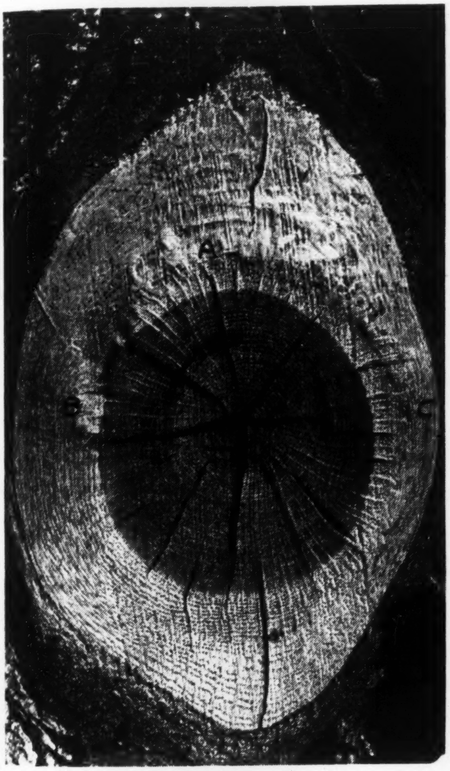

FIG. 2.

Second.—Checks on the face of a knot run radially from the pith center and those running to the sides never run beyond the knot without an abrupt change in direction.

To one trying to determine the size of a knot, the oaks give a great deal of trouble due to two principal causes: First, color cannot be depended upon to outline the knot, and second, the body of the oak tree is usually greatly enlarged at a limb and a large amount of irregular or burly growth is introduced by a cut through the knot.

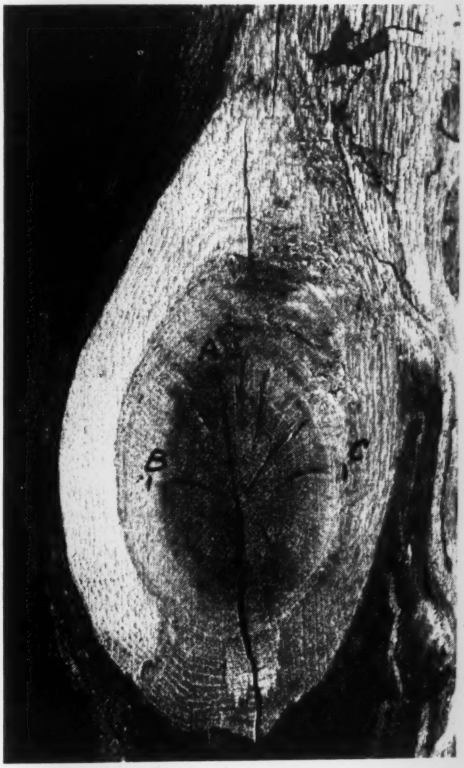

FIG. 3.

On the top of the oak knot it will usually be found that the very definite growth rings of the knot change very abruptly to burly irregular grain (see A, Fig. 2), often with bark pockets (see A, Fig. 3). This is the body wood above the knot. The radial checking in the oak knot is often very prominent and can be used to determine the limits of the knot. The checks follow the rays and run approximately radially from the pith center of the knots. The checks running to the bottom of the knot may run approximately straight far beyond the limit of the knot and occasionally those running to the top may run through the burly wood above the knot in more or less of a straight line, but the checks running to the sides of the knot, while they may stop short of the limit of the knot, never run without an abrupt change of direction beyond the limit of the knot (see B, Figs. 1 and 2).

REPORT OF COMMITTEE D-8

ON

BITUMINOUS WATERPROOFING AND ROOFING MATERIALS

Committee D-8 on Bituminous Waterproofing and Roofing Materials has held two meetings during the past year: in Atlantic City, N. J., on June 29, 1938, and in Columbus, Ohio, on March 8, 1939.

Subsequent to the 1938 annual meeting, Committee D-8 presented to the Society through Committee E-10 on Standards, a proposed revision of the Tentative Methods of Testing Films Deposited from Bituminous Emulsions (D 466 – 37 T). This revision was accepted[1] for publication on August 25, 1938, and appears in the 1938 *Proceedings*.[2]

NEW TENTATIVE STANDARDS

Tentative Specifications for Asphalt Mastic for Use in Waterproofing (Asphalt Cement, Mineral Filler, Mineral Aggregate).—In its 1938 annual report[3] Committee D-8 recommended for publication new tentative specifications under the above title to cover mastics prepared by mixing all of the mineral aggregate constituents, mineral filler, and the asphalt cement on the site of the work. These specifications were accepted and published as tentative under the A.S.T.M. designation D 491 – 38 T.[4] In the same report Committee D-8 also recommended that because of contemplated revisions, the Standard Specifications for Asphalt Mastic for Use in Waterproofing (D 169 – 25) and for Acid-Resisting Asphalt Mastic (D 223 – 30)[5] be reverted to tentative, this recommendation to become effective in 1939. During the past year, it has been found practicable to combine these three specifications (D 491 – 38 T, D 169 – 25, and D 223 – 30) into a single new specification which is herewith presented for publication as tentative[6] to replace the three existing specifications which it is recommended be withdrawn.

Tentative Recommended Practice for Accelerated Weathering Test of Bituminous Materials.—For some years past considerable need has existed for a standard weathering test for bituminous materials. Development of an entirely satisfactory method of procedure for conducting such a test has been exceedingly difficult, but Committee D-8 now believes that the recommended practice which it has developed will be generally useful and recommends it for publication as tentative.[7]

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[1] In submitting this revision to Committee E-10 on Standards, Committee D-8 reported results of the letter ballot vote as follows: Of a total membership of 59, 32 members returned their ballots, of whom 28 voted affirmatively, 0 negatively, 2 members marked their ballots "not voting," and 2 ballots were unmarked.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 992 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1034.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 418 (1938).

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 973 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 981.

[5] 1936 Book of A.S.T.M. Standards, Part II, pp. 1125, 1123.

[6] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part II.

[7] This recommended practice was accepted as tentative by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part II.

II. REVISIONS OF TENTATIVE STANDARDS

The committee recommends that the following tentative specifications be revised as indicated below and continued as tentative:

Tentative Specifications for Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 - 38 T):[8]

Section 3.—Change Paragraphs (*d*) and (*h*) to read as follows by the addition of the italicized figures and the omission of those in brackets:

> (*d*) The average net weight per square yard shall not be less than [11] *10* oz.
>
> (*h*) The average strength at 70 F. (21.1 C.) measured crosswise of the roll (that is, in the direction of the filling) shall not be less than [40] *50* lb.

Section 4 (*d*).—Change from its present form: namely,

> (*d*) The thread count per inch both in the direction of the warp and in the direction of the filling shall not be more than 36.

to read as follows:

> (*d*) The thread count per inch shall conform to the following requirements:

	Min.	Max.
Warp................	26	32
Filling..........	24	32

Tentative Specifications for Asphalt for Use in Constructing Built-Up Roof Coverings (D 312 - 37 T):[9]

Section 3.—In the table of requirements add a new item (*j*) to read: "(*j*) Flash point (Cleveland Open Cup)" with a minimum requirement of 375 F. for each of the three types of roofing.

III. TENTATIVE REVISIONS OF STANDARDS

In order to bring the following standard specifications up to date and in line with present practice, the committee recommends that the revisions indicated below be accepted for publication as tentative:

Standard Specifications for Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 - 27):[10]

Section 7.—Change from its present form: namely,

> 7. The fabricated bituminized felt shall confrom to the following requirements:
>
> (*a*) *Width of Roll.*—Either 36 or 32-in., as may be specified, ±$\frac{1}{4}$ in.
>
> (*b*) *Gross Weight per Roll.*—40 to 80 lb.
>
> (*c*) *Weight of Wrapping and Packing Material per Roll.*—Maximum, $\frac{1}{2}$ lb.
>
> (*d*) *Weight of Material per 100 sq. ft. Exclusive of Packing and Wrapping.*—14 lb. ±1 lb.
>
> (*e*) *Moisture.*—Maximum, 2.5 per cent of the net weight.
>
> (*f*) *Distillate,* per cent by weight to 210 C., calculated on extracted saturant, not more than 2.
>
> *Distillate,* per cent by weight to 235 C., calculated on extracted saturant, not more than 5.
>
> (*g*) *Pliability at 77 F. (25 C.).*—At least four strips out of five shall not crack when bent through 180 deg. over a $\frac{1}{16}$-in. mandrel.
>
> (*h*) *Saturant in Moisture-Free Felt.*—Minimum, 140 per cent by weight.

to read as follows:

> 7. The fabricated bituminized felt shall conform to the following requirements:
>
> *Width of Roll.*—Either 36 or 32-in., as may be specified, ±$\frac{1}{4}$ in.
>
> *Area of Roll.*—Minimum, 432 sq. ft.
>
> *Weight of Material per 100 sq. ft. Exclusive of Packing and Wrapping.*—Minimum, 14 lb.
>
> *Moisture.*—Maximum, 2.5 per cent of the net weight.
>
> *Average Breaking Strength at 77 F. (25 C.):*
>
> *With fiber grain.*—Minimum, 30 lb. (Note)
>
> *Across fiber grain.*—Minimum, 15 lb. (Note)
>
> *Pliability at 77 F. (25 C.).*—At least 8 out of 10 strips shall not crack when bent 90 deg. at a uniform speed over a rounded corner of $\frac{1}{2}$-in. radius.

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[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 980 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1006.

[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 930 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 983.

[10] 1936 Book of A.S.T.M. Standards, Part II, p. 1140.

Saturant in Moisture-Free Felt.—Minimum, 140 per cent by weight.

NOTE.—If samples fail to comply with the requirements for breaking strength immediately after sampling, a retest shall be made upon test specimens which have been suspended in free air at laboratory temperature for 72 hr. Material shall be accepted or rejected upon the basis of this retest.

(*b*) *Gross Weight per Roll.*—40 to 80 lb.

(*c*) *Weight of Wrapping and Packing Material per Roll.*—Maximum, ½ lb.

(*d*) *Weight of Material per 100 sq. ft. Exclusive of Packing and Wrapping.*—14 lb. ±1 lb.

(*e*) *Loss on Heating at 105° C. (221° F.) for 5 hours.*—Maximum, 2 per cent.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Asphalt Mastic for Use in Waterproofing (Asphalt Cement, Mineral Filler, Mineral Aggregate), to replace Specifications D 169, D 223, and D 491	36	1	2
Recommended Practice for Accelerated Weathering Test of Bituminous Materials	36	0	3
II. REVISIONS OF TENTATIVE STANDARDS			
Spec. for Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 - 38 T)	32	0	7
Spec. for Asphalt for Use in Constructing Built-Up Roof Coverings (D 312 - 37 T)	35	1	3
III. TENTATIVE REVISIONS OF STANDARDS			
Spec. for Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 - 27)	30	0	9
Spec. for Asphalt-Saturated Asbestos Felt for Use in Constructing Built-Up Roofs (D 250 - 27)	30	0	9

Standard Specifications for Asphalt-Saturated Asbestos Felt for Use in Constructing Built-Up Roofs (D 250 - 27):[11]

Title.—Add the words "in Waterproofing and" after the word "Use."

Section 1.—Change to read as follows by the addition of the italicized words:

1. These specifications cover asphalt-saturated asbestos felt, either 32 or 36 in. in width, composed of asbestos felt saturated, but not coated, with asphalt, for use *in the membrane system of waterproofing and* in the construction of built-up roofs.

Section 7.—Change from its present form: namely,

7. The fabricated bituminized felt shall conform to the following requirements:

(*a*) *Width of Roll.*—Either 36 or 32 in., as may be specified, ±¼ in.

(*f*) *Pliability at 77° F. (25° C.).*—Shall not crack when bent through 180 deg. over a $\frac{1}{16}$-in. mandrel.

(*g*) *Saturant in Moisture-Free Felt.*—Minimum, 50 per cent by weight.

to read as follows:

7. The fabricated bituminized felt shall conform to the following requirements:

Width of Roll.—Either 36 or 32 in., as may be specified, ±¼ in.

Area per Roll.—Minimum, 324 sq. ft.

Weight of Material per 100 sq. ft. Exclusive of Packing and Wrapping.—Minimum, 14 lb.

Loss on Heating at 105 C. (221 F.) for 5 hr.—Maximum, 5 per cent.

Pliability at 77 F. (25 C.).—At least 8 out of 10 strips shall not crack when bent 90 deg. at a uniform speed over a rounded corner of ½-in. radius.

IV. REVERSION OF STANDARDS TO TENTATIVE

In its 1938 annual report[12] Committee D-8 recommended that the following standards[13] be reverted to tentative, such recommendation to become effective in 1939. This change in status will accordingly be made this year together with certain editorial changes, as indicated below:

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[11] 1936 Book of A.S.T.M. Standards, Part II, p. 1120.

[12] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 418 (1938).

Standard Specifications for Bituminous Grout for Use in Waterproofing Above Ground Level (D 170 – 25), in Section 3 (*a*) reference to obsolete Specifications D 144 replaced by reference to Type B asphalt in Specifications D 449, and in Section 3 (*b*) reference to obsolete Specifications D 42 and D 200 replaced by reference to Type A pitch in Specifications D 450;

Standard Specifications for Bituminous Grout for Use in Waterproofing Below Ground Level (D 171 – 25), in Section 3 (*a*) reference to obsolete Specifications D 40 replaced by reference to Type A asphalt in Specifications D 449, and in Section 3 (*b*) reference to obsolete Specifications D 42 and D 200 replaced by reference to Type B pitch in Specifications D 450; and

Standard Methods of Testing Bituminous Mastics, Grouts and Like Mixtures (D 147 – 27):
Section 7.—Change from its present form: namely,

7. The benzol solution containing the asphalt shall be evaporated to a thick viscous liquid on a steam or water bath, then transferred to a steam oven at 105 C. (221 F.) until its weight is nearly equal to the percentage of asphalt calculated in accordance with Section 5. It shall then be transferred to a hot plate and heated carefully with stirring at a temperature not exceeding 121 C. (250 F.) until its weight is exactly that determined in accordance with Section 6.

to read as follows:

7. Until standard methods are available, recovery and preparation for test of the bituminous matter soluble in pure benzol extracted from asphalt mastics and grouts shall be made according to the procedure described in the paper "Method and Apparatus for the Recovery of Asphalt."[a]

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[a] Gene Abson, "Method and Apparatus for the Recovery of Asphalt," *Proceedings*, Am. Soc. Testing Mats. Vol. 33, Part II, p. 704 (1933).

V. STANDARD CONTINUED WITHOUT REVISION

The committee has reviewed the Standard Method of Test for Steam Distillation of Bituminous Protective Coatings (D 255 - 28) which has remained without revision for a number of years and approves retaining this standard in its present form.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 59 voting members; 39 members returned their ballots, with the results shown in Table I.

This report has been submitted to letter ballot of the committee which consists of 59 voting members; 39 members returned their ballots, of whom 37 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. M. WEISS,
Chairman.

PRÉVOST HUBBARD,
Secretary.

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[13] 1936 Book of A.S.T.M. Standards, Part II, pp. 1127, 1129, 1143.

EDITORIAL NOTE

Subsequent to the annual meeting Committee D-8 presented to the Society through Committee E-10 on Standards a proposed revision of the Tentative Specifications for Primer for Use with Asphalt in Dampproofing and Waterproofing Below and Above Ground Level (D 41 – 36 T). This recommendation was accepted by Committee E-10 on August 24, 1939, and the revised tentative specifications appear in the 1939 Book of A.S.T.M. Standards, Part II.

REPORT OF COMMITTEE D-9

ON

ELECTRICAL INSULATING MATERIALS

Committee D-9 on Electrical Insulating Materials held two meetings during the year and will hold a third during the annual meeting of the Society in June, 1939, in Atlantic City, N. J. The meetings were held in November, 1938, and March, 1939, with an average attendance of 71 members and 20 visitors. The subcommittees which are responsible for specific work have been very active during the year and considerable progress has been made. Several projects have reached the stage where definite recommendations have been made resulting in additions or changes in the standards for which Committee D-9 is responsible. There are also a number of other projects still under way which are mentioned briefly later in this report.

A joint meeting of the Advisory Committees of Committee D-9 and Committee D-20 on Plastics was held during the year. At this meeting the complete program of work of each committee was discussed, and in several projects it was found that there would probably be a duplication of work. In an effort to minimize duplication, it was agreed to interchange the minutes of the two committees.

Subsequent to the 1938 annual meeting, Committee D-9 presented to the Society through Committee E-10 on Standards a revision of the Tentative Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 38 T), a revision of the Tentative Method of Testing Pin-Type, Lime Glass Insulators (D 468 - 37 T), and recommended the withdrawal of the Tentative Method of Test for Saponification Number of Electrical Insulating Oils (Modified Baader Method) (D 438 - 36 T). These recommendations were accepted[1] by Committee E-10 on August 25, 1938, and the two tentative methods in their revised form appear in the 1938 *Proceedings*.[2]

RECOMMENDATIONS AFFECTING STANDARDS

As a result of the year's work, Committee D-9 is presenting revisions of three tentative standards, and is recommending the adoption as standard of three tentative standards and tentative revisions of three existing standards; also tentative revisions in three new standards are submitted. The recommendations being presented are included in detail in Appendix I, each proposed revision being accompanied by a brief explanation of the reason for the revision together with data indicating the scope of the investigations substantiating the recommendations. The standards affected are listed in Table I.

Committee D-2 on Petroleum Products and Lubricants is recommending a revision[3] of the Tentative Methods of Test for Saponification Number (D 94 – 38 T) which methods are under the joint jurisdiction of Committees D-2 and D-9. Committee D-9 wishes to record its concurrence with this recommendation.

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[1] In submitting these recommendations to Committee E-10 on Standards, Committee D-9 reported the following results of the letter ballot vote from a committee membership of 88: D 229 - 38 T, ballots returned 46, affirmative 27, negative 0, ballots marked "not voting" 19; D 468 - 38 T, ballots returned 49, affirmative 18, negative 3, ballots marked "not voting" 28; D 438 - 36 T, ballots returned 45, affirmative 26, negative 0, ballots marked "not voting" 19.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1046, 1037 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1181, 1140.

The recommendations have been submitted to letter ballot of the committee which consists of 92 voting members, the results being given in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISIONS OF TENTATIVE STANDARDS			
Test for Dielectric Strength of Insulating Materials, at Commercial Power Frequencies (D 149 – 38 T)	41	1	15
Spec. for Black Bias-Cut Varnished Cloth Tape Used for Electrical Insulation (D 373 – 37 T)	25	1	31
Testing Pin-Type, Lime Glass Insulators (D 468 – 38 T)	17	2	39
II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 38 T)	35	1	19
Testing Laminated Tubes Used in Electrical Insulation (D 348 – 38 T)	32	1	22
Testing Laminated Round Rods Used in Electrical Insulation (D 349 – 35 T), as revised	29	1	25
III. TENTATIVE REVISIONS OF STANDARDS			
Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 39)	34	1	20
Testing Laminated Tubes Used in Electrical Insulation (D 348 – 39)	34	0	21
Testing Laminated Round Rods Used in Electrical Insulation (D 349 – 39)	31	0	24
IV. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Testing Molded Materials Used for Electrical Insulation (D 48 – 37)	34	1	21
Methods of Testing Electrical Porcelain (D 116 – 34)	31	0	0
Methods of Testing Pasted Mica Used Electrical Insulation (D 352 – 36)	31	0	0

ACTIVITIES OF SUBCOMMITTEES

Since a large part of the work of the subcommittees consists of obtaining data and studying results, it is only possible in one year to submit definite recommendations on a small portion of the work. It is felt desirable to mention briefly some of the other projects which have engaged the attention of the subcommittees, but which as yet have not reached the stage where definite recommendations have resulted.

Subcommittee I on Insulating Varnishes, Paints, and Lacquers (C. F. Hanson, Chairman).—Work is still in progress in an attempt to develop a suitable method for determining the set time of phenolic resins.

The subject of impregnating varnishes has been reported upon in the last five or six years and the work is still in progress with a view to developing an apparatus and testing procedure for determining the impregnating properties and the internal drying of saturating varnishes.

An inter-laboratory test is under way with a view to developing a standard method of test for determining resistance of varnishes to acid, alkalies, and sea water.

The subject of drying time of varnish is still active. Attention is being given to the development and procurement of suitable ovens of two different types. One type of oven would be used for obtaining the drying time of baking varnishes and the other type would be used for obtaining the drying time of air-drying varnishes.

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[3] This revision was accepted by the Society and has been incorporated in the methods which appear in the 1939 Book of A.S.T.M. Standards, Part III.

Subcommittee II on Molded Insulating Materials (W. A. Evans, chairman).—A proposed tentative method of test for measuring shrinkage from mold size has been prepared and is expected to be submitted to the committee sometime during the year.

Three standard molds are being developed to be used for producing bar and disk specimens. These designs are expected to be completed during this year for inclusion in the various test methods.

The tracking test method which has been under development is now practically complete and the results are expected to culminate in a new tentative method which will probably be ready for action by the committee at the annual meeting.

The work on conditioning of thermoplastic test specimens is being continued.

Subcommittee III on Plates, Tubes, and Rods (Dean Harvey, chairman).—Methods of conditioning sheet, rod, and tube materials to insure reproducibility of mechanical tests are being recommended for adoption as mentioned elsewhere in this report, and methods of conditioning the same materials for electrical tests are now being developed.

The Rockwell hardness test using scale M is not satisfactory for the softer grades of stiff sheet materials, and work is being done to determine the limiting hardness below which should be used the R scale Rockwell test in which a larger ball penetrator is employed.

Tests showing the relation between Rockwell hardness of heated specimens and the actual punching qualities have been made to determine whether the Rockwell test can be used as an indication of punching quality, and the data are being summarized.

An investigation has been made of the suitability of eleven different tests as a means of checking product uniformity by several laboratories on paper-base phenolic laminated sheets, purposely varied in the manufacturing process. The data are being studied. Similar tests are planned for fabric-base sheets.

Proposed specifications for phenolic laminated tubes for radio use have been prepared and distributed for comment.

Test work is under way on a proposed method of test for power factor of phenolic laminated sheets parallel to laminations. Methods of testing vulcanized tubing are also under consideration.

An investigation is being made of a method of testing electrical insulating materials for tracking resistance which has been proposed by the Association of Edison Illuminating Cos.

Subcommittee IV on Insulating Mineral Oils (E. A. Snyder, chairman).—A revised program has been outlined on the development of a suitable sludge accumulation test for insulating oils, and an oxidation test under pressure is also being investigated. Samples of oil to be used in these tests are now in the hands of several laboratories.

Work is being done in connection with the preparation of an evaporation test, and samples have been forwarded to several laboratories. The round-robin tests for power factor, dielectric constant, and resistivity are being continued.

The present work on gas content of oil indicates that temperature affects the gas content; therefore, a further study will be required.

The dielectric strength test procedure is being revised and will be presented during the year. Additional work is to be undertaken in connection with the preparation of the test specimen and momentary discharges.

A new section has been created which is to revise the scope of the sub-committee. Several recommendations have been presented which include the following: (*1*) Confine its activities to liquid insulation, (*2*) Utilize the same methods for all liquid insulation wherever possible, and (*3*) Not to include in its present work treated or composite materials. The new section is planning to include in its study test methods for liquid insulation in which the liquid is derived from sources other than petroleum oils.

As a result of power factor measurements in several laboratories certain requirements of the cells have been found necessary. These requirements are given in Appendix II.

Subcommittee IV is continuing as tentative the revision of the Standard Methods of Testing Electrical Insulating Oils (D 117 – 36), dealing with the determination of color of insulating oils. This revision refers to the Tentative Method of Test for Color of Lubricating Oils by Means of A.S.T.M. Union Colorimeter (D 155 – 38 T), which method is being revised by Committee D-2 this year.

Subcommittee V on Ceramic Products (*Porcelain, Glass, etc.*) (L. E. Barringer, chairman).—The study of measurements of power factor and dielectric constant of titania ceramic bodies is being continued, also the preparation of methods for the testing of steatitic ceramic bodies. There is also under consideration the adoption of a porosity test by the dye penetration method. The method under consideration is that being revised by the National Electrical Manufacturers Association and the American Institute of Electrical Engineers.

A round-robin series of tests which has been under way in several laboratories is nearing completion. These tests include power factor and dielectric constant measurements on samples of five different glasses. The range of frequency originally outlined covered 60 cycles to 1 megacycle, but has now been extended to 20 megacycles.

The Section on Glass Insulators is considering the advisability of preparing methods for testing low-expansion glass insulators and methods to be used for secondary racking spools.

Subcommittee VII on Electrical Tests (J. A. Scott, chairman).—The round-robin tests of power factor of oil samples, using the Committee D-9 cell, are still being carried out. Plans are being made to circulate a standard capacitor with a shielded series resistor to secure a comparison of the accuracy of the measuring equipment.

The round-robin tests of power factor of mica flakes are being continued, and the method is giving satisfactory results. Work on bakelite disks and on laminated materials measured parallel to the laminations is being continued. It is planned to give further study to the effect of moisture causing increased power factor at low frequencies.

Round-robin tests of the measurement of power factor at ultra high frequencies are being carried out on Styrene, Mycalex, hard rubber, and phenolic laminated materials.

Work at the National Bureau of Standards has led to further refinement in the calculation of edge effect in the measurement of power factor when unguarded electrodes are used. The results of this work are being presented as a revision of the Tentative Methods of Testing Electrical Insulating Materials for Power Factor and Dielectric Constant (D 150 – 36 T).

The Tentative Methods of Test for Conducting Paths in Electrical Slate (D 273 – 36 T), has been on a tentative basis for three years without revision; however, the subcommittee recommends that it continue as tentative.

The Tentative Method of Test for Comparing the Thermal Conductivities of Solid Electrical Insulating Materials (D 325 – 31 T), has remained as tentative for eight years; however, since there is little use for this method the subcommittee recommends that it continue as tentative. It is proposed to survey the usage of this method during the coming year.

Subcommittee VIII on Insulating Papers and Fabrics (Treated and Untreated) (R. W. Chadbourn, chairman).—Division I on Untreated Paper has developed a method for determining the rate of oil penetration in insulating papers and is revising the method for the determination of conducting paths. Attempts to interest the Institute of Paper Chemistry in undertaking the investigation of the problem of extraction of the acid in paper have been fruitful, and the Institute has finally agreed to sponsor such a research. The problem of coordination of activities of the Technical Association of the Pulp and Paper Industry, Committee D-6 on Paper and Paper Products, and Subcommittee VIII has been solved by the appointment of a Joint Committee on Paper Testing Methods, composed of representatives from T.A.P.P.I. and Committee D-6, to which matters of difference will be referred, matters involving Subcommittee VIII being first referred to Committee D-6.

The Section on Thickness is continuing its study of the dial micrometer and the newly developed machinist's micrometer with controlled spring and in view of this the Tentative Methods of Test for Thickness of Solid Electrical Insulation (D 374 – 36 T), are being continued as tentative.

Division II on Treated Fabrics has undertaken a canvass of the industry to determine the extent of use of the existing specifications for varnished cambric tape and to solicit criticisms thereof. Correlation of A.S.T.M. specifications with the new N.E.M.A. specifications will later be attempted. The Section on Varnished Tubing is revising the test methods and specifications for varnished tubing to include saturated sleeving. The tests at elevated temperatures are being materially revised.

Subcommittee IX on Mica Products (M. P. Davis, chairman).—The round-robin tests for power factor and dielectric constant are being continued. Several laboratories have reported results, and samples and electrodes are being sent to other laboratories for test. The study of purchase specifications is being continued. The preparation of color photographic plates for use in the classification of mica is also being continued. A request has been received from the radio tube manufacturers relative to measurements of hole sizes and punched sheets.

Subcommittee X on Conditioning (Robert Burns, chairman).—Work is being continued on a standard conditioning chamber, which will eliminate some of the variables now existing in the unusually wide choice of equipment and which will permit a higher degree of conformance between testing laboratories. Progress has been reported on definitions and nomenclature, and a definition of "room temperature" will probably be submitted during the year. A new section was created which is aiding Committee D-20 on Plastics in the selection of conditioning requirements for tensile and flexural strength tests.

Special Subcommittee on Significance of Tests (Dean Harvey, chairman).—In order to hasten the completion of other sections for the report on Significance of Tests of Electrical Insulating Materials,[4] each subcommittee has been asked to appoint a special group to study its present methods and to prepare a statement of the significance of these tests. In addition, the subcommittee is also preparing sections on several items.

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 436 (1937); Vol. 38, Part I, p. 432 (1938).

This report has been submitted to letter ballot of the committee which consists of 92 voting members; 59 members returned their ballots, of whom 44 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

T. SMITH TAYLOR,
Chairman.

E. J. RUTAN,
Secretary.

EDITORIAL NOTE

Subsequent to the annual meeting, Committee D-9 presented the recommendations listed below to the Society on October 7, 1939, through Committee E-10 on Standards, all of which were accepted. The new methods were assigned the A.S.T.M. serial designations indicated. These and the new revised tentative standards and tentative revisions of standards are published in the 1939 Book of A.S.T.M. Standards, Part III.

New Tentative Methods of:

Testing Secondary Glass Spool Insulators (D 550 – 39 T), and

Measuring Shrinkage from Mold Dimensions of Molded Materials Used for Electrical Insulation (D 551 – 39 T).

Proposed Revision of Tentative Methods of Testing:

Varnishes Used for Electrical Insulation (D 115 – 38 T),

Electrical Insulating Materials for Power Factor and Dielectric Constant (D 150 – 36 T),

Untreated Paper Used in Electrical Insulation (D 202 – 38 T),

Flexible Varnished Tubing Used for Electrical Insulation (D 350 – 38 T),

Pin-Type, Lime Glass Insulators (D 468 – 39 T).

Proposed Tentative Revisions of Standard Methods of:

Testing Molded Materials Used for Electrical Insulation (D 48 – 39), and

Test for Grading and Classification of Natural Mica (D 351 – 38) in the form of new Tentative Method of Test for Power Factor and Dielectric Constant of Natural Mica, to be added when adopted to the present standard.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS FOR ELECTRICAL INSULATING MATERIALS

In this Appendix are given recommendations affecting certain standards and tentative standards covering electrical insulating materials which are referred to earlier in this report.[1] In connection with each title is given the reference to the publication in which the standard appears in its present form.

REVISIONS OF TENTATIVE STANDARDS

Tentative Methods of Test for Dielectric Strength of Insulating Materials, at Commercial Power Frequencies (D 149 - 38 T):[2]

Several minor changes are being recommended by Subcommittee VII in Section 3 on Electrical Apparatus, as follows:

Section 3.—Change the fourth and fifth sentences of Paragraph (*a*) to read as follows by the addition of the italicized words and the omission of those in brackets:

> For test specimens of small capacitance, *a testing transformer as small as 500 volt-ampere rating or* a well-designed potential transformer may be adequate. For specimens of high capacitance, a transformer of [several] *ample* kilovolt-ampere rating [may be necessary] *must be used.*

Following Paragraph (*a*) add a note to read as follows:

> NOTE.—When a transformer is used at voltages lower than its full rating, the current drawn from the high voltage winding should not exceed the full-load full-voltage current rating.

Change Paragraph (*c*) from its present form: namely,

> (*c*) *Voltage Control.*—The rate of voltage rise shall not, for short-time tests, vary more than plus or minus 25 per cent from the specified rate. Control of voltage may be secured in one of several ways: (*1*) generator-field regulation, (*2*) induction regulator, (*3*) variable-ratio auto-transformer, or (*4*) resistance-potential divider. In general, variable-ratio auto-transformers or resistance-potential dividers have better voltage-time characteristics than induction regulators and furnish the most satisfactory means of regulation on constant potential sources of supply, where the volt-ampere demand is low. Motor drive, with variable speed control, should be preferred to manual drive because of the difficulty of maintaining reasonably uniform rate of voltage rise with the latter.
>
> NOTE.—A small variable auto-transformer, motor controlled, with automatic limit features, is described in the Appendix.

to read as follows:

> (*c*) *Voltage Control.*—The rate of voltage rise shall not, for short-time tests, vary more than plus or minus 25 per cent from the specified rate. Control of voltage may be secured in one of several ways: (*1*) variable-ratio auto-transformer, (*2*) resistance-potential divider, (*3*) generator-field regulation, or (*4*) induction regulator. Preference should be given to equipment having an approximately straight-line voltage-time curve over the desired operating range. Motor drive, with variable speed control, should be preferred to manual drive because of the difficulty of maintaining reasonably uniform rate of voltage rise with the latter.

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[1] See p. 451.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1001 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1063.

NOTE.—A small variable auto-transformer, motor controlled, with automatic limit features, is described in the Appendix.

Change the last sentence of Paragraph (*d*), and Paragraph (*e*) to read as follows by the addition of the italicized words and the omission of those in brackets:

> A voltmeter connected to the low-voltage side of the testing transformer [or to a tertiary coil] may be used only if the ratio of transformation does not change appreciably with load [or if the voltmeter corrects or compensates for variations in load].
>
> (*e*) *Rate of Rise of* Voltage [Rate Indicator].—The rate of voltage rise may be [determined by some such device as a "rate-of-rise" indicator or by measuring the] *calculated from measurements of* time required to raise the voltage between two prescribed values. When motor-driven regulating equipment is used, the speed-control rheostat may be calibrated in terms of voltage rise for any particular test transformer.

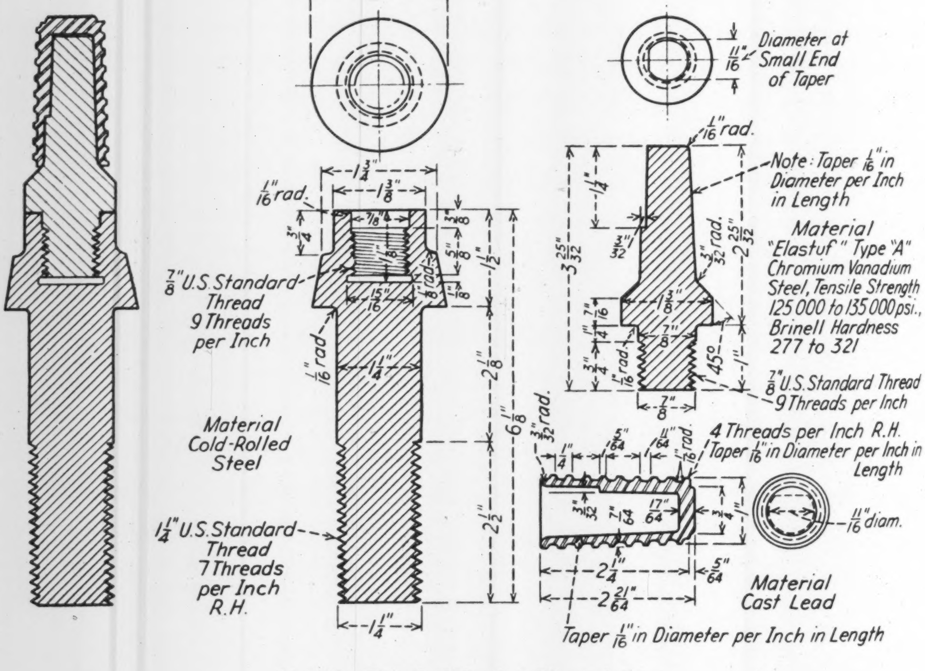
2"
1 3/4"
1 3/8"
1/16" rad.
3/4"
7/8"
3/8"
5/8"
1 1/2"
1/8" rad.
1/8"
15/16"
7/8" U.S. Standard Thread 9 Threads per Inch
1/16" rad.
1 1/4"
2 1/8"
6 1/8"
Material Cold-Rolled Steel
1 1/4" U.S. Standard Thread 7 Threads per Inch R.H.
2 1/2"
1 1/4"
11/16" Diameter at Small End of Taper
1/16" rad.
Note: Taper 1/16" in Diameter per Inch in Length
1 1/4"
Material "Elastuf" Type "A" Chromium Vanadium Steel, Tensile Strength 125 000 to 135 000 psi., Brinell Hardness 277 to 321
3 25/32"
2 25/32"
3/32"
3/32" rad.
1 3/8"
7/16"
1/4"
7/8"
45°
1"
3/4"
1/16" rad.
7/8"
7/8" U.S. Standard Thread 9 Threads per Inch
3/32" rad.
1/4"
5/64"
11/64"
1/16" rad.
4 Threads per Inch R.H.
Taper 1/16" in Diameter per Inch in Length
3/32"
7/64"
17/64"
3/4"
1"
11/16" diam.
2 1/4"
5/64"
2 21/64"
Material Cast Lead
Taper 1/16" in Diameter per Inch in Length

FIG. 1.—Detail of Testing Pin and Cap.

Tentative Specifications for Black Bias-Cut Varnished Cloth Tape Used for Electrical Insulation (D 373 – 37 T):[3]

Subcommittee VIII on Insulating Papers and Fabrics is recommending the elimination of Section 10 on Flexibility, because the requirement is not sufficiently well-defined and reproducible and in its present form unnecessarily handicaps the manufacturer. It is proposed to substitute for this, after further study, a more accurate procedure.

Section 10.—Omit this section which reads as follows, renumbering the subsequent sections accordingly:

> 10. The varnish coating shall be flexible and shall not crack when the tape is doubled upon

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[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 979 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 1051.

itself and creased between the thumb and index finger. Care shall be taken not to bring the finger nails into contact with the tape surfaces while making the crease.

Tentative Methods of Testing Pin-Type, Lime Glass Insulators (D 468 – 38 T):[4]

During the past year it has been found necessary to make only several minor changes in these methods. However, the Section on Glass Insulators is not recommending their adoption as standard at the present time because it is now considering the relative advisibility of including provisions for testing low-expansion glasses in the present methods or of writing a separate test method for such glasses. The minor revisions being recommended at this time are as follows:

Section 1.—Change to read as follows by the addition of the italicized words:

> 1. These methods are intended to apply to the testing of pin-type, lime glass insulators used for primary and secondary power distribution *to 10,000 v. to ground.*

Section 3.—In the first sentence, change the order of the tests so that the thermal shock test precedes gaging for pin-hole formation.

Sections 5 and 6.—Interchange these sections to conform to the revised order of tests in Section 3.

Figure 1.—Replace this figure, which shows the detail of pin and cap for the mechanical strength test, by the accompanying Fig. 1.

Section 7.—Change the first sentence to read as follows by the addition of the italicized words:

> The insulators shall be mounted on a lead (containing not over 5 per cent antimony) threaded steel pin (Fig. 1), *with mounting similar to that shown*, of sufficient strength to prevent permanent deflection during the pull required to fail the insulator.

In the fourth sentence, change the specified speed of the testing machine from "0.050 in. per min." to read "0.25 in. per min."

Section 8.—In the heading and first sentence, change the words "dielectric strength" to read "dielectric breakdown."

Appendix II.—In the title and opening paragraph change the words "dielectric strength" to read "dielectric breakdown." Wherever the words "dielectric strength" or "puncture" occur in the body of the appendix, add in parenthesis the words "dielectric breakdown." The original phraseology is being retained in the body of the appendix as it is a quotation from an A.I.E.E. standard.

ADOPTION OF TENTATIVE STANDARDS AS STANDARD

Tentative Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 38 T):[5]

The committee recommends that these methods be approved for reference to letter ballot of the Society for adoption as standard, but submits the following revisions for publication as tentative:

Section 4.—Add a new Section 4 to read as follows, renumbering the subsequent sections accordingly:

> 4. *Conditioning for Reproducibility* (Note 1).—In order to eliminate the effect of previous history of humidity exposure and to obtain reproducible results, the test specimens of flat sheet materials shall be given a conditioning treatment for physical (Note 2) tests as follows:
>
> (*a*) *Impact Strength.*—The machined specimens of all types of sheet, excepting cellulose esters, shall be conditioned prior to test by drying in an air-circulated oven at 50 ± 3 C. (122 ± 5 F.) for 48 hr., followed by cooling to room temperature in a desiccator containing calcium chloride or an approximate equivalent drying agent for a period of not over 24 hr. The cellulose ester specimens shall be conditioned for 96 hr. at the 50 C. temperature. All

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1037 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1140.

[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I p. 1046 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1181.

specimens shall be tested at room temperature maintained at 25 ± 8 C.

(*b*) *Tensile, Flexural, Compressive, and Bonding Strengths, Rockwell Hardness, and Density.*—The following conditioning treatment shall be used for the various types of materials, in each case cooling to room temperature in a desiccator following the conditioning. Specimens shall be kept in the desiccator until ready for test. Tests shall be made at room temperature maintained at 25 ± 8 C. except where closer limits are specified.

Cellulose Esters.—All specimens conditioned for 96 hr. at 50 ± 3 C.

Hard Rubber, Phenolic Laminated and Other Sheets Bonded with Thermosetting Resins.—No conditioning of specimens except in case of dispute, in which case the specimens shall be conditioned for 48 hr. at 50 ± 3 C.

Vulcanized Fiber, Pressboard, Other Cellulosic Boards, Asbestos Boards, Sheets with Non-Thermosetting Resinous Binders, and All Other Sheets Not Previously Included.—All specimens conditioned for 48 hr. at 50 ± 3 C.

NOTE 1.—Conditioning of specimens may be undertaken: (*a*) for the purpose of bringing the material into equilibrium with standard normal conditions, 25 C. and 40 per cent relative humidity; (*b*) simply to obtain reproducible results, irrespective of previous history of exposure; or (*c*) to subject the material to abnormal conditions of temperature or humidity in order to predict its service behavior.

The conditions given here to obtain reproducible results may give physical values somewhat higher or somewhat lower than values under equilibrium at normal conditions, depending upon the particular material and test. To insure substantial equilibrium under normal conditions of humidity and temperature, however, will require from 20 to 100 days or more depending upon thickness and type of material and its previous history. Consequently, conditioning for reproducibility must of necessity be used for general purchase specifications and product control tests.

NOTE 2.—Conditioning of specimens for electrical tests is also necessary to obtain consistent results. The procedure for such conditioning is under consideration by the committee. In order to secure comparative results, specimens should be conditioned at the same temperature and humidity.

Further changes in the method, necessitated by the above additions, are as follows:

Delete Sections 6, 11 (*a*), and 37 (*a*) covering temperature of tests, Note 2 under Section 17, Notes under Sections 40 and 41 (*d*), and Section 42 (*d*).

Add new Sections 16 (*f*) and 38 (*c*) to read: "The room temperature."

Section 43 (*a*).—Change from its present form: namely,

> 43. (*a*) *Fiber 0.020 in. or less in Thickness.*—For vulcanized fiber 0.020 in. or less in thickness the specimen shall be dried in an oven for 2 hr. at 105 to 110 C. It shall then be weighed on a chemical balance accurate to 0.25 per cent. The thickness shall be determined after drying. The apparent density shall be calculated from the thickness and the weight by means of the following formula:
>
> $$\text{Apparent Density, g. per cu. cm.} = \frac{\text{Weight in grams}}{\text{Volume in cu. in.}} \times 0.061$$

to read as follows:

> 43. (*a*) *Fiber 0.020 in. or less in Thickness.*—For vulcanized fiber 0.020 in. or less in thickness, the specimen after conditioning shall be weighed on a chemical balance accurate to 0.25 per cent. The thickness shall then be measured and the apparent density calculated from the thickness and weight by means of the following formula:
>
> $$\text{Apparent Density, g. per cu. cm.} = \frac{\text{wt. in grams}}{\text{vol. in cu. in.}} \times 0.061$$

Section 53.—Change from its present form: namely,

> (53) The test specimens shall be conditioned for 24 hr. at 105 C. before test.

to read as follows:

> (53) The test specimens shall be conditioned for 48 hr. at 50 ± 3 C. prior to test, followed by cooling to room temperature in a dessicator. Tests shall be made at room temperature maintained at 25 ± 8 C.

Tentative Methods of Testing Laminated Tubes Used in Electrical Insulation (D 348 – 38 T):[6]

The committee recommends that these methods be approved for reference to letter ballot of the Society for adoption as standard, but submits the following revisions for publication as tentative:

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[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1009 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1153.

Section 2.—Add a new Section 2 to read as follows, renumbering the subsequent sections accordingly:

2. *Conditioning for Reproducibility* (Note 1).—In order to eliminate the effects of previous history of humidity exposure and to obtain reproducible results, the test specimens of laminated tubes shall be given a conditioning treatment for physical (Note 2) tests as follows:

(*a*) *Diametrical Compressive Strength.*—The machined specimens shall be conditioned prior to test by drying in an air-circulated oven at 50 ± 3 C. (122 ± 5 F.) for 48 hr., followed by cooling to room temperature in a desiccator. All specimens shall be tested at room temperature maintained at 25 ± 8 C.

(*b*) *Tensile and Axial Compressive Strength, Density.*—No conditioning of specimens is required except in case of dispute, in which case the specimens shall be conditioned for 48 hr. at 50 ± 3 C.

NOTES 1 AND 2.—See Notes 1 and 2 appearing above in the proposed revision of Methods D 229.

Tentative Methods of Testing Laminated Round Rods Used in Electrical Insulation (D 349 - 35 T):[7]

The committee recommends that these methods, revised as follows, be approved for reference to letter ballot of the Society for adoption as standard:

Since the 1-in. length now specified in the test method is too long to permit the testing of material ¼ in. in diameter or less, it is recommended that Section 13 be changed from its present form: namely,

13. Samples shall be tested as received in specimen lengths of 1 in. The ends shall be accurately cut or ground square with the sides

to read as follows:

13. Samples shall be tested as received in specimen lengths as follows:

Diameter, In.	Length
⅛ to ¼	½ in.
Over ¼ to 1½	1 in.

For rods over 1½ in. in diameter, specimens shall be 1-in. cubes cut from the rods so as to be representative of its cross-section both at the center and near the edges.

The ends of the specimens shall be accurately cut or ground square with the sides.

Section 15.—Add the following as a new Paragraph (*b*), relettering the present Paragraphs (*b*) and (*c*) as (*c*) and (*d*):

(*b*) When 1-in. cube specimens are used, the dimensions and approximate location of each with reference to area of rod section.

The following revisions of Method D 349, upon its adoption as standard, are accordingly submitted for publication as tentative:

Section 2.—Add a new Section 2 to read as follows, renumbering the subsequent sections accordingly:

2. *Conditioning for Reproducibility* (Note 1).—In order to eliminate the effects of previous history of humidity exposure and to obtain reproducible results, the test specimens of laminated rods shall in all cases of dispute be given a conditioning treatment for physical (Note 2) tests as follows:

(*a*) *Tensile, Flexural, and Compressive Strengths, and Density.*—Prior to test the machined specimens shall be conditioned by drying in an air-circulated oven at 50 ± 3 C. (122 ± 5 F.) for 48 hr., followed by cooling to room temperature in a desiccator. All specimens shall be tested at room temperature maintained at 25 ± 8 C.

NOTES 1 AND 2.—See Notes 1 and 2 appearing above in the proposed revision of Methods D 229.

Section 5.—Omit this section covering temperature of tests, renumbering the subsequent sections accordingly.

ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

Standard Methods of Testing Molded Materials Used for Electrical Insulation (D 48 - 37):[8]

The committee recommends that the tentative revision of these methods published last year[9] covering changes in the dielectric strength test procedure be referred to letter ballot of the Society for adoption as standard.

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[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 1026 (1935); also 1938 Book of A.S.T.M. Tentative Standards, p. 1149.

[8] 1937 Supplement to Book of A.S.T.M. Standards, p. 232.

Standard Methods of Testing Electrical Porcelain (D 116 – 34):[10]

The committee recommends that the tentative revision[9] of these methods covering changes in the scope be referred to the Society for adoption as standard.

Standard Methods of Testing Pasted Mica Used in Electrical Insulation (D 352 – 36):[10]

The committee recommends that the tentative revision[9] of these methods covering changes in the procedure for determining stability under heat and pressure and the dielectric strength test procedure be referred to the Society for adoption as standard.

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[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1337, 1338 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1703, 1704.

[10] 1936 Book of A.S.T.M. Standards, Part II, pp. 1178, 1216.

APPENDIX II

REQUIREMENTS FOR CELLS USED FOR MEASURING LOW POWER FACTOR LIQUIDS

The electrical capacitance of the power factor cell when filled with a liquid to be tested shall be of such magnitude that power factor differences of the order of 1×10^{-6} may be detected on the bridge used.

The design of the cell shall be such as to facilitate easy and thorough cleaning. The design, also, shall conveniently permit the use of the cell in a suitable temperature bath and means shall be provided for measuring the temperature of both electrodes.

The materials used in constructing the cell shall be capable of satisfactorily withstanding temperatures up to 130 C. and the alignment of the electrodes shall not be influenced by this temperature.

The electrodes or their surfaces shall be made of a metal capable of resisting attack by mild acids found in certain insulating liquids such as petroleum oil, particularly after prolonged exposure at elevated temperatures. Metals which have been found satisfactory from this standpoint are gold, nickel, monel, and platinum. In general, plated surfaces have been found less satisfactory than solid metal electrodes for measuring low power factor liquids. Plated surfaces that may be satisfactory for testing liquids with low acidity and for short periods of time are gold, platinum, nickel, chromium over nickel, or rhodium.

A guard electrode shall be provided and shall completely surround the measuring electrode except at the measuring surface. A shielded wire or coaxial cable shall be used to connect the guard and measuring electrode either directly or by a plug to the bridge.

The gap between the measuring electrodes and the guard shall be free of solid insulation. (Insulation in this space has been found undesirable both because of the difficulty in making it sufficiently tight to prevent contamination from one measurement to another and because of an effect due to dielectric loss variations in the guard gap region.)

The insulating materials used in constructing the cell shall not absorb or be adversely affected by the test liquids, or cleaning solvents. Their power factor is preferably low, particularly that between the guard and high-voltage electrodes, otherwise difficulty may be experienced in balancing the guard circuits at elevated temperatures. Insulating materials that have proven satisfactory are pyrex glass, quartz, steatite, and the better phenolic resin compounds. Thermoplastic materials such as hard rubber and polystyrene, although having good electrical properties, are not suitable as they soften below 130 C. Insulating materials of the molded mica-dust type have been found to absorb solvents and therefore may not be satisfactory in the measurements of low power factor liquids. However, they are excellent materials for supporting the cell in the temperature bath.

In designing the cell the distance

across the surface of the oil and across the solid insulating material, between the guard and the high voltage electrode, shall be great enough adequately to withstand the testing potential used. Leakage across these paths has been found to produce an unsteady bridge balance on some bridges.

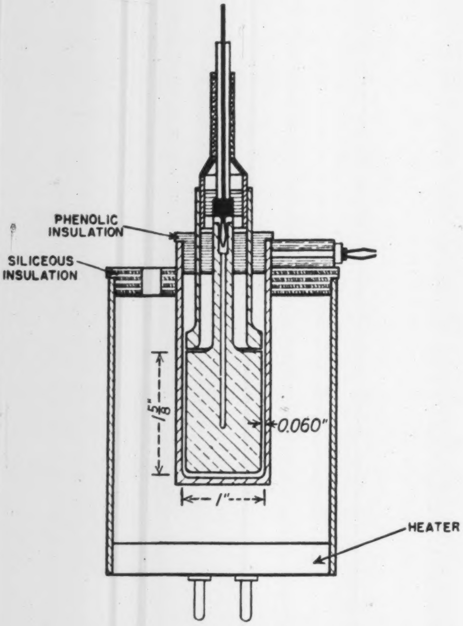

FIG. 1.—Power Factor Cell With Heater.

A cell and heater bath design that is available and used successfully by several testing laboratories is shown in Fig. 1. Its volume is 8 ml. The voltage limit is 1000 v. and the capacitance with oil having a dielectric constant of 2.2 is about 60 $\mu\mu$f.

For routine work cells on the same design principles, with particular attention to quickness of assembly and suitable for higher voltages may be desirable. Several laboratories use cell designs similar to Fig. 2 which are commercially available. This design requires about 90 ml. of oil and is suitable for use up to 3 kv., the capacitance with oil being about 180 $\mu\mu$f.

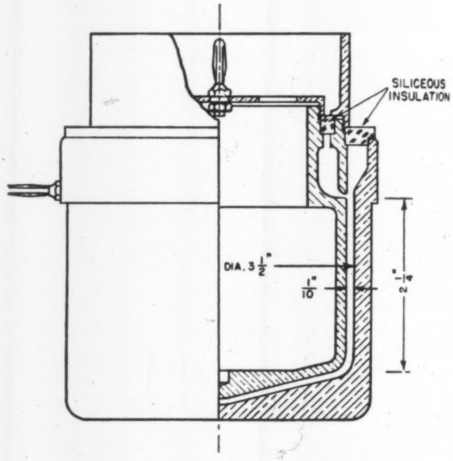

FIG. 2.—Power Factor Cell.

REPORT OF COMMITTEE D-11

ON

RUBBER PRODUCTS

Committee D-11 on Rubber Products has been very active during the year and has made considerable progress in its standardization work although only one meeting has been held since the one during the 1938 annual meeting. This was in Columbus, Ohio, on March 8, 1939, in connection with the spring group meetings of A.S.T.M. committees.

During the year there have been a number of changes in the personnel of the committee. P. L. Wormeley of the National Bureau of Standards, who was one of the original organizers of the committee and a member of the Advisory Committee, found it necessary to resign from active membership but, in response to unanimous request, has consented to continue his association as a consulting member. W. E. Emley, however, is now actively representing the National Bureau of Standards on the committee, replacing Mr. Wormeley on the Advisory Committee.

New members of the committee include: R. J. Allen, Worthington Pump and Machinery Corp.; C. F. Bullard, Eastman Kodak Co.; Ralph T. K. Cornwell, Sylvania Industrial Corp.; H. P. Hagedorn, Bureau of Engineering, City of Chicago; W. F. Markley, Western Union Telegraph Co.; G. W. Oxley, Standard Oil Development Co.; G. L. Roberts, United Carbon Co.; P. S. Vormelker, Aetna Rubber Co.; Fred Wehmer, Minnesota Mining and Manufacturing Co.; H. P. Hass has replaced F. T. Quinlan as representative of the New York, New Haven, and Hartford Railroad Co.; and G. E. Hopkins, of the Bigelow Sanford Carpet Co., has resigned.

Subsequent to the 1938 annual meeting, Committee D-11 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Method of Test for Resistance to Light Checking and Cracking of Rubber Compounds (D 518 - 38 T),

Revision of Tentative Methods of Testing Rubber Insulated Wire and Cable (D 470 - 38 T),

Tentative revision of Standard Methods of Chemical Analysis of Rubber Products (D 297 - 38), and

Tentative revision of Standard Method of Test for Hardness of Rubber (D 314 - 34).

The new Methods of Test for Resistance to Light Checking and Cracking (D 518 - 38 T) are part of the program referred to in the 1938 annual report[1] for standardizing methods for light tests of rubber. These deal only with sunlight aging and incorporate procedures reduced to standard form covering the present usual practice. It is expected later to extend this work to include tests using artificial light. The revisions of the Methods for Testing Rubber Insulated Wire and Cable (D 470 - 38 T) were also discussed in last year's annual report[1] and provide for the separation of the test methods from the actual wire specifications. The tentative revision of the Standard Methods of Chemical Analysis (D 297 – 38) covers a change in value for specific gravity of rubber hydrocarbon from "0.94" to "0.92" since the latter is considered to be a more accurate average value for use in calculations. The tentative revision of the Standard Method of Test for Hardness of Rubber (D 314 – 34) gives a definite sequence of operation of applying the pressure foot and indentor of the test instrument. This change has become necessary in order to assure uniform procedure when using different designs of instruments, all of which comply with the requirements of the method and have now become available. These recommendations were accepted[2] by Committee E-10 on August 25, 1938, and appear in the 1938 *Proceedings*.[3]

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 447, 449 (1938).

I. NEW TENTATIVE STANDARDS

Tentative Specifications for Rubber Sheath Compound for Electrical Insulated Cords and Cables.—These specifications have been developed by Subcommittee V on Insulated Wire and Cable in order to provide standards for tough rubber sheath compounds for use on portable cords and cables. The need for such specifications has been discussed in previous reports but their development was retarded because of difficulty in finding suitable tests to measure resistance of the rubber sheath to abrasion and tearing. It is to be noted that these specifications include requirements covering age deterioration and resistance to tear, although the question of resistance to abrasion has had to be omitted for the present except as indirectly covered by requirements for minimum tensile strength. In presenting these specifications the committee is aware that in their proposed form they still do not completely and adequately cover this test problem. It is believed, however, that the need for the specifications is so great as to justify their acceptance for publication as tentative; the specifications represent the best practice it is possible to submit in the present state of the art. It is expected that further work will be done looking toward improvement of these specifications, the results of which will be presented as revisions when they become available. The committee accordingly recommends that the new Specifications for Rubber Sheath Compound for Electric Cords and Cables be accepted for publication as tentative.[4]

Tentative Methods of Testing Hard Rubber Products.—These methods have been developed by Subcommittee XXIII on Hard Rubber and are intended to provide a recommended procedure in standard consolidated form for testing all sorts of products made from the material ordinarily classed as "hard rubber." This material is understood to refer to vulcanized rubber compositions having a ratio of combined sulfur to rubber hydrocarbon in excess of 15 per cent. In general, the test methods used for soft, flexible rubber products are not suitable for use with this hard inelastic material, and separate test procedures are therefore required. The proposed tentative methods include reference to applicable procedures for chemical analysis as well as detailed descriptions of tests for both physical and electrical properties. The committee recommends that the new Methods of Testing Hard Rubber Products be accepted for publication as tentative.[5, 6]

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[2] In submitting these recommendations to Committee E-10 on Standards, Committee D-11 reported the following results of the letter ballot vote of a total of 56 ballots returned from a committee membership of 102: D 518 – 38 T, affirmative 48, negative 0, ballots marked "not voting" 8; D 470 – 38 T, affirmative 40, negative 0, ballots marked "not voting" 16; D 297 – 38, affirmative 51, negative 0, ballots marked "not voting" 5; D 314 – 34, affirmative 48, negative 0, ballots marked "not voting" 8.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1139, 1127, 1332, 1333 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1355, 1386, 1698, 1699.

[4] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

[5] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

[6] See Editorial Note, p. 475.

Tentative Method of Test for Indentation of Rubber by Means of Pusey and Jones Plastometer.—This tentative method has been prepared by Subcommittee XVII on Rubber Products for Absorbing Vibration to provide a standard procedure for use of the Pusey and Jones plastometer in measuring the indentation of vulcanized rubber compounds. The use of the word "hardness" has purposely been avoided in the method to prevent confusion with the present Standard Method of Test for Hardness of Rubber (D 314 - 34). The Pusey and Jones method is very generally in use in the paper industry in connection with rubber-covered rolls and similar products and has also found wide application in other fields, being required in many specifications promulgated by the Federal Government. While it might be considered desirable for purposes of standardization to try to induce all users of indentation tests to follow the present Standard Method D 314, this does not seem practical at the present time in view of the familiarity in some industries with the use for many years of the Pusey and Jones instrument. Since it is recognized that this instrument will continue to be used and, in some cases, has certain advantages, it has seemed desirable to the committee to provide a standard procedure for conducting tests employing it. The committee therefore recommends that the Method of Test for Indentation of Rubber by Means of Pusey and Jones Plastometer be accepted for publication as tentative.[5]

II. REVISIONS OF TENTATIVE STANDARDS

The committee is proposing revisions of four tentative methods of test and three tentative specifications as indicated below, and recommends that as revised they be continued as tentative.

Tentative Methods for Testing Flat Rubber Belting (D 378 - 38 T):[7]

Section 3 (c).—Change this section to provide for the use of a 3-oz. load in place of a 9-oz. load on the dial gage.

Section 10 (d).—In order to eliminate adhesion testing on thin covers, since tests made under these conditions are entirely unreliable because of excessive stretch and breakage of the rubber cover, it is recommended that the first sentence be changed to read as follows by the addition of the italicized words:

> The adhesion between the rubber covers and the body of the belt shall be determined on the test specimen prepared for ply adhesion *except that no tests for cover adhesion shall be made on rubber covers less than $\frac{3}{64}$ in. in thickness.*

Tentative Methods of Testing Rubber Hose (D 380 - 38 T):[7]

Section 4 (a).—Change this section to provide for the use of a 3-oz. load in place of a 9-oz. load on the dial gage.

Section 21.—The procedure for the gasoline immersion swelling test as given at present is not satisfactory because of the failure to weigh the swelled sample in air. The results as calculated, therefore, do not give a proper measure of the percentage increase in apparent volume of the specimen. It is accordingly recommended that the next to the last sentence of Paragraph (*b*) be changed by the addition of the italicized words and the omission of those in brackets, and add before the last sentence a new sentence, as follows:

> At the termination of the immersion period, the specimen shall be removed from the gasoline, dipped in 95 per cent ethyl alcohol, blotted lightly with filter paper, and [immediately weighed in distilled water (W_3) as before] *placed in a tared weighing bottle and weighed (W_3). It shall then be removed from the bottle*

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[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1105, 1114 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1364, 1373.

and weighed (W_4) in distilled water in immediate consecutive procedure to determine the water displacement after test.

Change Paragraph (*c*) from its present form to read as follows:

(*c*) *Calculation.*—The volume increase shall be calculated as follows:

Increase in Volume, per cent

$$= \frac{(W_3 - W_4) - (W_1 - W_2)}{(W_1 - W_2)} \times 100$$

Tentative Methods of Tension Testing of Vulcanized Rubber (D 412 – 36 T):[8]

Section 4.—Add a new Paragraph (*g*) to read as follows:

(*g*) The tension testing machine may be equipped with a dynamometer head of the compensating type for convenience in eliminating calculations.

Section 8.—Add a note to this section to read as follows:

NOTE.—It is a well known fact that vulcanized rubber exhibits a grain effect which influences its physical properties. In the case of heavily loaded compounds the effect may produce a pronounced difference in physical properties. Laboratory practice is to test with the grain, and it is assumed that unless otherwise specified all test specimens are to be prepared in this manner. Where grain effects are significant and are to be evaluated, two sets of test specimens should be cut at right angles to each other.

Section 9.—Letter the present section as Paragraph (*a*), and add as Paragraph (*b*) the present note concerning choice of dies given under Fig. 3.

Section 11 (*a*).—Change this section to provide for the use of a 3-oz. load in place of a 9-oz. load on the dial gage. It is intended that this change shall apply to other rubber standards requiring use of the 9-oz. dial micrometer. The 3-oz. weight is in agreement with the standard practice of the American Chemical Society and the Federal Specifications Executive Committee. The committee has demonstrated to its satisfaction that the use of the lighter weight gives a more reliable measure of thickness when working with a wide range of hardnesses of rubber compounds.

Section 13 (*b*).—Omit the last sentence which reads as follows:

A tension testing machine equipped with a dynamometer head of the compensating type is convenient in eliminating calculations and its use is permitted in stress-strain tests.

Tentative Methods of Testing Rubber Insulated Wire and Cable (D 470 – 38 T):[9]

New Sections.—Add new Sections 33 to 37, inclusive, covering the flame test, moisture test, and mineral filler content determination.[10]

Tentative Specifications for Insulated Wire and Cable: Class AO, 30 per cent Hevea Rubber Compound (D 27 – 38 T):[9]

Section 21 (*b*).—Change from its present form to read as follows:

(*b*) *Shielding.*—Wires and cables not supported on insulators shall be shielded or suitably protected against corona in accordance with the detailed recommendations contained in Sections 24 to 28, inclusive.

New Sections.—Following Section 23 add new Sections 24 to 28, inclusive,[11] covering Shielding, renumbering the subsequent sections accordingly.

Sections 33 to 37.—Replace the sections covering Finish with new Sections 38 to 49, inclusive,[11] renumbering the subsequent sections accordingly.

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[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 1105 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 1287.

[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1127, 1143 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1386, 1245.

[10] This revision was accepted by the Society and has been incorporated in the methods which appear in the 1939 Book of A.S.T.M. Standards, Part III.

[11] These revisions were accepted by the Society and have been incorporated in the specifications which appear in the 1939 Book of A.S.T.M. Standards, Part III.

Tentative Specifications for Insulated Wire and Cable: Performance Rubber Compound (D 353 – 37 T):[13]

Section 7.—Replace the present requirements for shielding with the new sections on shielding as recommended above in Specifications D 27 – 38 T.

Section 7.—Replace the present requirements for shielding with the new sections on shielding as recommended above in Specifications D 27 – 38 T.

Table III.—Replace the table on insulation resistance with the accompanying Table I, in which the values are based on a constant K equal to 15,840 in place of the constant 21,120 used in the present table in the specifications.

TABLE I.—INSULATION RESISTANCE.

Insulation Thickness in Sixty-fourths of an Inch	2	3	4	5	6	7	8	9	10	12	13	14	15	16	17
Size of Conductor, A.w.g. numbers or circular mils	Insulation Resistance, megohms—1000 ft. at 60 F. (15 5.C.)														
No. 18	6450	8350	....	....	....	....	....	....	....	....	....	....	....	....	....
No. 16	5500	7150	....	....	....	....	....	....	....	....	....	....	....	....	....
No. 14	....	6250	7450	8500	9400	10 200	10 950	11 600	12 200	13 200	....	....	....	....	....
No. 12	....	5300	6400	7400	8250	9 000	9 700	10 300	10 900	11 900	....	....	....	....	....
No. 10	....	4500	5500	6400	7200	7 900	8 500	9 100	9 650	10 600	....	....	....	....	....
No. 8	....	....	4650	5500	6250	6 850	7 450	8 000	8 500	9 400	9850	10 200	10 600	10 950	11 200
No. 6	....	....	3550	4200	4800	5 400	5 900	6 380	6 850	7 650	8000	8 350	8 650	9 000	9 350
No. 4	....	....	2900	3500	4100	4 600	5 000	5 450	5 850	6 650	7000	7 300	7 600	7 900	8 200
No. 2	....	....	2450	2950	3400	3 850	4 250	4 600	5 000	5 700	5950	6 300	6 600	6 850	7 150
No. 1	....	....	....	2650	3100	3 500	3 900	4 200	4 600	5 200	5500	5 750	6 000	6 300	6 550
No. 0	....	....	....	2400	2800	3 150	3 500	3 850	4 150	4 750	5050	5 300	5 550	5 850	6 100
No. 00	....	....	....	2200	2550	2 900	3 200	3 500	3 800	4 400	4650	4 900	5 200	5 360	5 650
No. 000	....	....	....	1950	2350	2 600	2 900	3 200	3 500	4 050	4300	4 600	4 750	5 000	5 200
No. 0000	....	....	....	1800	2100	2 350	2 700	2 900	3 150	3 700	3900	4 150	4 350	4 550	4 750
250 000 cir. mils	....	....	....	....	1950	2 200	2 500	2 750	3 000	3 450	3700	3 900	4 100	4 300	4 450
350 000 cir. mils	....	....	....	....	1700	1 900	2 150	2 350	2 600	3 000	3200	3 400	3 550	3 770	3 900
500 000 cir. mils	....	....	....	....	1400	1 650	1 850	2 050	2 200	2 600	2800	2 950	3 100	3 250	3 400
750 000 cir. mils	....	....	....	....	....	1 350	1 550	1 700	1 900	2 200	2300	2 500	2 650	2 800	2 900
1 000 000 cir. mils	....	....	....	....	....	1 200	1 350	1 500	1 650	1 950	2050	2 200	2 300	2 500	2 600
1 250 000 cir. mils	....	....	....	....	....	....	1 200	1 350	1 500	1 750	1900	2 000	2 150	2 250	2 350
1 500 000 cir. mils	....	....	....	....	....	....	1 100	1 250	1 400	1 600	1700	1 850	1 950	2 050	2 200
1 750 000 cir. mils	....	....	....	....	....	....	1 050	1 160	1 300	1 500	1600	1 750	1 850	1 950	2 050
2 000 000 cir. mils	....	....	....	....	....	....	1 000	1 100	1 200	1 400	1550	1 650	1 750	1 850	1 950

NOTE.—This table is based on a constant, $K = 15{,}840$ in the following formula:

$$R = K \log_{10} \frac{D}{d}$$

where:

R = insulation resistance in megohms—1000 ft.,
K = constant,
D = diameter over insulation, on each conductor, and
d = diameter over conductor.

Tentative Specifications for Insulated Wire and Cable: Heat-Resisting Rubber Compound (D 469 – 37 T):[13]

Table I.—Change the requirement for the 504-hr. oxygen pressure test to read as follows by the addition of the italicized words and figures and the omission of the figure in brackets:

> Depreciation in tensile strength and elongation after [504] *168* hr., *at 80 C. and 300 lb. pressure*, oxygen pressure test, max., per cent.................................. 25.

III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the tentative methods listed below be approved for reference to letter ballot of the Society for adoption as standard. These methods have had a tentative status for three years or more with either none or very minor criticism, and are believed to be satisfactory.

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[13] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, pp. 1109, 1096 (1937); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1259, 1265.

Tentative Methods of:

Sample Preparation for Physical Testing of Rubber Products (D 15 – 38 T),[14]

Test for Adhesion of Vulcanized Rubber (Friction Test) (D 413 – 36 T),[15] and

Test for Adhesion of Vulcanized Rubber to Metal (D 429 – 36 T).[15]

IV. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

No objection has been received to the tentative revisions[16] of the following standards, approved for publication by Committee E-10 on Standards last year, and as both are considered highly essential, the committee recommends that these revisions be adopted as standard and asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society.

Standard Methods of:

Test for Hardness of Rubber (D 314 – 34), and

Chemical Analysis of Rubber Products (D 297 – 38).

V. WITHDRAWAL OF TENTATIVE STANDARD

The committee recommends that the Tentative Specifications for Rubber Pump Valves (D 151 – 31 T)[17] be withdrawn. A section of Subcommittee VI has completed an investigation of the status of these tentative specifications and has reported that they are not being used for the purchase of material and there appears now to be no demand for or interest in the trade in specifications for this product. It is not contemplated to undertake further work for modernization or improvement of these specifications because of the lack of interest.

VI. STANDARDS AND TENTATIVE STANDARDS CONTINUED WITHOUT REVISION

The committee desires that all tentative standards under its jurisdiction not mentioned in this report be continued as tentative without revision. The Tentative Methods of Test for Accelerated Aging of Vulcanized Rubber (D 428 – 36 T) have had a tentative status for three years without revision. Changes are under consideration, however, as mentioned later in this report, and it is desirable to continue the methods in their present form until an agreement is reached. The Tentative Methods of Test for Flexing of Rubber Products (D 430 – 35 T) have stood in this status for four years. The matter of adopting the methods as standard has been considered by the committee and it has been decided that they be continued in their present form to permit further consideration of possible changes.

The Standard Specifications for Rubber Matting for Use Around Electrical Apparatus or Circuits not Exceeding 3000 Volts to Ground (D 178 – 24) have been reviewed and a few minor editorial changes are expected to be made but, in general, these specifications are still considered satisfactory without major revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 105 members; 67 members returned their ballots, with the results shown in Table II.

ACTIVITIES OF SUBCOMMITTEES

Discussion of the activities of the subcommittees of Committee D-11 will be limited to the consideration of a few of the more important projects in progress. It should be understood, however, that all of these subcommittees are active in their respective fields.

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[14] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1099 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1281.

[15] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, pp. 1120, 1127 (1936); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1307, 1314.

[16] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1332, 1333 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1698, 1699.

[17] *Proceedings*, Am. Soc. Testing Mats., Vol. 31, Part I, p. 944 (1931); also 1938 Book of A.S.T.M. Tentative Standards, p. 1279.

Advisory Committee (O. M. Hayden, chairman).—Early in 1939 the suggestion was made by the Society of Automotive Engineers that there is urgent need for development of standards for rubber products used by the automotive industry. For some years, Committee D-11 has endeavored to meet this need in the present subcommittee organization but rapid progress has been handicapped by lack of cooperation from the consumer interests in the automotive industry, by decentralization of the activities over a number of subcommittees in Committee D-11, and by the undeveloped state of standardization of certain test methods covering fundamental properties of rubber applicable to all materials including automotive products.

TABLE II.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Rubber Sheath Compound for Electrical Insulated Cords and Cables	36	0	31
Testing Hard Rubber Products	38	0	29
Method of Test for Indentation of Rubber by Means of Pusey and Jones Plastometer	40	0	27
II. REVISIONS OF TENTATIVE STANDARDS			
Testing Flat Rubber Belting (D 378 - 38 T)	33	0	34
Testing Rubber Hose (D 380 - 38 T)	35	0	32
Tension Testing of Vulcanized Rubber (D 412 - 36 T)	51	0	16
Testing Rubber Insulated Wire and Cable (D 470 - 38 T)	38	0	29
Spec. for Insulated Wire and Cable: Class AO, 30 per cent Hevea Rubber Compound (D 27 - 38 T)	37	0	30
Spec. for Insulated Wire and Cable: Performance Rubber Compound (D 353 - 37 T)	37	0	30
Spec. for Insulated Wire and Cable: Heat-Resisting Rubber Compound (D 469 - 37 T)	36	1	30
III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Sample Preparation for Physical Testing of Rubber Products (D 15 - 38 T)	54	0	13
Test for Adhesion of Vulcanized Rubber (Friction Test) (D 413 - 36 T)	49	0	18
Test for Adhesion of Vulcanized Rubber to Metal (D 429 - 36 T)	43	0	24
IV. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Test for Hardness of Rubber (D 314 - 34)	47	0	20
Chemical Analysis of Rubber Products (D 297 - 38)	50	1	16
V. WITHDRAWAL OF TENTATIVE STANDARD			
Spec. for Rubber Pump Valves (D 151 - 31 T)	33	0	34

Committee D-11 has actively been endeavoring for some years to overcome the latter handicap and has made substantial progress. It is felt that the time is now ripe for concentration specifically upon development of automotive rubber standards as suggested by the Society of Automotive Engineers. It is also believed that their proposal will insure better cooperation of the automotive engineers than has been obtainable in the past. The Advisory Committee has, therefore, proposed that the project of developing automotive rubber standards be centralized in a technical committee, of which the personnel will be drawn jointly from the present membership of Committee D-11 and representatives of the major consuming interests in the automotive industry as recommended by the S.A.E. This proposal has been approved by Committee D-11 and the new technical committee is now in process of organization. It will be known as Technical Committee A on Automotive Rubber Products.

Subcommittee VI on Packings, Gaskets, and Pump Valves (William Staniar, chairman).—This subcommittee in its Section on Classification has prepared an extensive outline of various classes of packings and gaskets to serve as a guide for future subcommittee activities, copy of which is appended to this report. The subcommittee has selected certain of the more important items included in this classification for its first attention. These include particularly Items I (A, B, C) covering rubber sheet, compressed asbestos sheet, and cloth inserted sheet packings. Sections have been organized to handle the preparation of standards for these products and are actively at work. Another section of the subcommittee has been engaged in studying the status of specification buying of products under the jurisdiction of the committee. A large amount of information has been assembled relative to the test methods which are currently in use for specifying the properties of these materials. In line with the present policy of Committee D-11, preparation of standards by the subcommittee will be limited for the present, at least, to the development of satisfactory test methods rather than to the preparation of materials specifications, and particular attention will be given to performance tests designed to evaluate properties related to service. Another section of the subcommittee has completed an investigation of the status of the present Tentative Specifications for Rubber Pump Valves (D 151 - 31 T), reporting that these specifications should be withdrawn, as recommended earlier in this report.

Subcommittee IX on Insulating Tape (W. H. S. Youry, chairman).—The Specifications for Friction Tape for General Use for Electrical Purposes (D 69 - 38), under the jurisdiction of this subcommittee, were recommended for submission to the American Standards Association for approval as American standard. Objection was raised by the railroad interests to the cold-adhesion value, which is specified at present as not more than 15-in. separation under the prescribed conditions of test. The railroad group has, in the past, considered that it needed a somewhat different tape for signal work and the suggestion was made that the permissible rate of separation be lowered to a value not in excess of 8 in. Because of this objection, approval of these specifications has been held up. The matter has been the subject of much discussion in the subcommittee which is now giving consideration to the possibility of changing the requirement to provide for a rate of separation of 8 ±4 in. per min., in the hope that such a requirement would meet the needs of both those using friction tape for general work and those interested in signal work, as well as conforming to good manufacturing practice.

Subcommittee X on Physical Testing of Rubber Products (H. M. Frecker, chairman).—This subcommittee, in addition to recommending the changes in standards under its jurisdiction which are mentioned earlier in this report, is conducting a survey by means of a questionnaire in order to secure data from a large number of laboratories on possible improvements in the Methods of Tension Testing of Vulcanized Rubber (D 412 - 36 T) and to arrive at possible revisions with respect to the present provisions covering the interpretation of results of tension tests. This question of interpretation includes statistical methods of handling results from duplicate specimens as well as standard provisions for discarding and averaging the results of individual tests. In view of the importance of tension tests in rubber testing, this matter is of great importance not only to this subcommittee but also in connection with life tests and various other procedures where tensile strength is used as an index of change in other properties.

Subcommittee XI on Chemical Analysis of Rubber Products (S. Collier, chairman).—This subcommittee has completed its investigation of recommended methods for the determination of small amounts of manganese and copper in rubber which was mentioned in last year's report.[18] The analytical data from the various laboratories cooperating varied as much as 500 per cent on manganese and 100 per cent on copper. The subcommittee has, therefore, decided that the present available methods are inadequate and has authorized a section to proceed with further study and to write a new procedure to cover these determinations. When this work is completed a new cooperative study of proposals developed will be initiated. The subcommittee has also been giving consideration to the present analytical procedures in the Standard Methods of Chemical Analysis of Rubber Products (D 297 - 38) and is of the opinion that the methods now included are inadequate and, in some cases, out of line with best modern practice. The subcommittee has therefore authorized appointment of a section to study, rewrite, and submit for cooperative testing a completely revised procedure covering chemical methods for use in rubber analysis.

Subcommittee XIV on Abrasion Tests for Rubber Products (G. S. Haslam, chairman).—The committee has approved the inclusion of a note following Table I of the Tentative Methods of Test for Abrasion Resistance of Rubber Compounds (D 394 - 37 T) stating that "Comparison standard specimens of compound B having certified physical properties for use in this procedure may be obtained from the laboratory of V. L. Smithers, Inc., First Central Tower, Akron, Ohio."

Subcommittee XV on Life Tests for Rubber Products (J. H. Ingmanson, chairman).—The section of this subcommittee appointed to study the Method for Air Pressure Heat Test for Vulcanized Rubber (D 454 - 37 T), under the chairmanship of G. S. Haslam, has completed its report. Fifteen laboratories cooperated in this program and a large amount of detailed data has been accumulated. Cooperative tests comparing the various forms of apparatus in use in the several laboratories were carried out and the data have been submitted to a statistical analysis. From consideration of all of this work, the section has drawn the following conclusions:

1. That Method D 454 - 37 T provides a satisfactory test for the determination of the life of rubber compounds under the conditions specified,
2. That any laboratory with proper attention to the procedure outlined should be able to reproduce the results of any other laboratory within a reasonable limit of error,
3. That no further refinement on apparatus is required at this time, and
4. That further cooperative tests are unnecessary for the present.

The subcommittee is organizing two new sections: one on development of kinetic aging tests under artificial light, and the other on interpretation of test data. The subcommittee has had numerous requests for a standard procedure for carrying out accelerated aging tests in the laboratory using artificial light. Tests of this sort are frequently employed at present but there is very little standardization. The effect of light on rubber in producing deterioration and cracking is well known. Some means of evaluating this, rapidly and positively, which can be followed by all laboratories in a standard way, is very much needed. The section on interpretation of test data will cooperate so far as life tests are concerned in similar work being undertaken by Subcommittee X, as already mentioned. Subcommittee XV has received numerous suggestions that the temperature and pressure conditions at present specified in the Tentative Methods of Tests for Accelerated Aging of Vulcanized Rubber (D 428 - 36 T) are in need of revision. The principal reason for these suggestions is the desire further to accelerate the tests so as to secure results in a shorter time. Some users of these tests have already adopted higher temperature conditions for the air oven aging test, and others have been experimenting with higher temperatures and lower oxygen pressures in the oxygen pressure chamber aging test. Considerable data relating to these proposals have been presented to the subcommittee, which has organized a section to consider the question of changing the temperature and pressure requirements in these procedures. In view of this work the subcommittee has decided to withhold for the present any recommendation for the adoption as standard of methods D 428 - 36 T.

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[18] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 448 (1938).

Subcommittee XVII on Rubber Products for Absorbing Vibration (J. J. Allen, chairman).—This subcommittee has given considerable attention to a further study of the Tentative Methods of Test for Compression Set of Vulcanized Rubber (D 395 - 37 T). Although these methods are in quite common use, difficulty is still experienced in duplicating results closely in different laboratories. For this reason it has been decided that a further detailed investigation should be carried out in the subcommittee before recommending adoption of the tentative methods as standard. A section has been authorized to do this work, with instructions to make definite recommendations after studying the various details of the procedures, including both the method of measuring thickness and the matter of using decay of load as an index of set rather than change in dimensions.

Subcommittee XVIII on Dynamic Fatigue Testing for Rubber Products (E. B. Curtis, chairman).—This subcommittee is preparing new methods of test for the effect of compression hysteresis on vulcanized rubber. It was expected to have these methods ready for inclusion in this report but this has not been found possible and it is now anticipated that they will be offered to the Society through Committee E-10 on Standards after the annual meeting. These methods have for their objective the evaluation of rubber compounds with respect to deterioration from heat produced by hysteresis in rapid cyclic compression flexing. The failures ultimately result in blowout rather than ply separation or cracking and are therefore used for an entirely different class of goods than the bending or stretching tests. The procedures are of great value in evaluating rubber products which fail in service in a manner similar to that occurring during the test, and are applied to many products, including particularly vibration absorbers used in compression or shear and also automobile tires.

Subcommittee XXI on Tests of Liquid Rubber Products (L. M. Freeman, chairman).—This subcommittee has completed comparative tests in five different laboratories on methods for determining viscosity of cement. Four samples of cement, covering a range of viscosity from thin to thick, were checked in all laboratories, each of which determined total solids and viscosity by their own procedures. As a result, viscosities were obtained by ten different instruments. Two laboratories using two different types of viscosimeters checked very closely. These viscosimeters were those known as the falling-cylinder type and the funnel type. All results of total solids determination checked closely. Further tests were then made using the two viscosimeters, and in these cases the viscosities of the specimens were varied by other means than change in solids content. After studying the data from these tests, the subcommittee has decided to prepare tentative procedures for total solids determination and also for viscosity determination with both the falling-cylinder and the funnel type methods. It is anticipated that these procedures will be available in the near future.

Subcommittee XXII on Sponge Rubber (L. P. Gould, chairman).—This subcommittee has completed its organization and is actively at work on the preparation of standard procedures for testing sponge rubber. A questionnaire has been prepared covering controversial points on certain tests procedures, including those for compression set, tensile strength, and elongation. The subcommittee has also under consideration a preliminary draft of a proposed tentative method of testing sponge rubber.

This report has been submitted, to letter ballot of the committee which consists of 105 members; 67 members returned their ballots, of whom 60 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

O. M. HAYDEN,
Chairman.

ARTHUR W. CARPENTER,
Secretary.

EDITORIAL NOTE

Subsequent to the annual meeting Committee D-11 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Methods of Testing Sponge Rubber Products (D 552 - 39 T),

New Tentative Methods of Test for Viscosity and Total Solids Content of Rubber Cements (D 553 - 39 T), and

Proposed Revision of Tentative Methods of Testing Hard Rubber Products (D 530 - 39 T).

These recommendations were accepted by Committee E-10 on Standards on September 5, 1939, and the new and revised tentative methods appear in the 1939 Book of A.S.T.M. Standards, Part III, bearing the designations indicated.

REPORT OF SPECIAL SECTION ON PACKING CLASSIFICATION

Subcommittee VI on Packings, Gaskets, and Pump Valves

A proposal for a classification of rubber-containing gaskets, valve disks, sliding contact packings, and diaphragms to be employed in the future proceedings of Subcommittee VI is submitted, as follows:

I. Gaskets (including sheet or strip from which gaskets are intended to be cut):

A. Rubber compounds without fabric reinforcement or a high percentage of fiber.

B. Rubber compounds with a high percentage of fiber.

C. Rubber compounds with fabric reinforcement.

1. Cotton fabric:
   (*a*) Sheet (or strip cut from sheet),
   (*b*) Rolled or folded strip, and
   (*c*) Gaskets prepared from preceding forms with or without subsequent molding.

2. Asbestos fabric:
   (*a*) Sheet (or strip cut from sheet),
   (*b*) Rolled or folded strip, and
   (*c*) Gaskets prepared from preceding forms with or without subsequent molding.

3. Wire fabric (sheet only).

D. Rubber compounds with reinforcement of twisted or braided asbestos yarns.

II. Valve Disks:

A. Rubber compounds without fabric reinforcement or high percentage of fiber.

B. Rubber compounds with a high percentage of fiber.

C. Rubber compounds with fabric reinforcement.

III. Sliding Contact Packings (including sheet or strip from which rings, etc., are intended to be cut):

A. Rubber compounds without fabric reinforcement or high percentage of fiber.

B. Rubber compounds with high percentage of fiber.

C. Rubber compounds with fabric reinforcement.

1. Cotton fabric:
   (*a*) Sheet (or strip cut from sheet),
   (*b*) Rolled or folded strip, and
   (*c*) Rings (or other forms) prepared from preceding forms with or without subsequent molding.

2. Asbestos fabric:
   (*a*) Sheet (or strip cut from sheet),
   (*b*) Rolled or folded strip, and
   (*c*) Rings (or other forms) prepared from preceding forms with or without subsequent molding.

D. Rubber compounds reinforced with twisted or braided yarns, wires or metal foil strips.

IV. Diaphragms (including sheet from which diaphragms are intended to be cut):

A. Rubber compounds without fabric reinforcement.

B. Rubber compounds with fabric reinforcement.

1. Cotton fabric:
   - (*a*) Sheet (or strip cut from sheet), and
   - (*b*) Diaphragms molded from preceding forms.
2. Asbestos fabric:
   - (*a*) Sheet (or strip cut from sheet), and
   - (*b*) Diaphragms molded from preceding forms.

Respectfully submitted on behalf of the special section,

F. C. THORN, *Chairman*
H. P. HASS
U. S. NAVY BUREAU OF CONSTRUCTION AND REPAIR

REPORT OF COMMITTEE D-12

ON

SOAPS AND OTHER DETERGENTS

Committee D-12 on Soaps and Other Detergents held two well-attended and interesting meetings during the year: one on October 31–November 1, 1938, and the second on March 27–28, 1939, both at the Hotel New Yorker, New York City.

At the spring meeting, W. D. Pohle, of the Naval Stores Research Division of the U.S. Bureau of Chemistry and Soils, gave an address descriptive of his work on rosin and rosin soaps, which was very interesting.

The committee records with regret the death of one of its members, Frederick Kenney. Mr. Kenney has been a very valuable member of the committee, particularly because of his experience acquired by his long service as chief chemist of the City of New York.

C. A. Marlies has been selected as chairman of Subcommittee III on Nomenclature and Definitions, in place of the late Mr. Kenney, and also as the representative of Committee D-12 on the Society's General Committee on Nomenclature. C. L. Nutting has been named as the representative of the American Association of Textile Chemists and Colorists on Committee D-12. L. B. Hitchcock has been designated as a member of the Advisory Committee to succeed G. E. Hopkins, resigned.

The following new members were elected to Committee D-12 during the year:

F. D. Snell, Brooklyn, N. Y.
R. B. Mears, Aluminum Co. of America, New Kensington, Pa.
H. H. High, E. F. Houghton and Co., Philadelphia, Pa.
J. K. Stewart, Anderson Pritchard Co., Chicago, Ill.
J. A. Jenemann, E. I. du Pont de Nemours and Co., Grasselli Chemicals Dept., Wilmington, Del.

During the year the following members resigned: F. R. Gunn, G. E. Hopkins, G. H. Johnson, D. R. McIver, H. S. McQuaid, and Samuel Meeker.

W. G. Morse has been named editor of a proposed monograph, to be descriptive of some of the detergents, their tests, and uses. A new Subcommittee IV on Publications, consisting of the following, has been appointed to handle all papers and publications sponsored by the committee, and in particular to advise the scope and character of the proposed monograph:

W. H. Koch, chairman
A. G. Aitchison
J. B. Crowe
R. E. Devine
B. H. Gilmore
J. A. Jenemann
W. H. Joy
Israel Katz
J. W. McBain
W. G. Morse
R. H. Sawens
M. L. Sheely
B. S. Van Zile
C. C. Zeigler

In addition to the work completed to date, the committee is considering the preparation of specifications and methods of test for liquid and paste soaps, scouring powders and soaps, and other phosphates and silicates. It is also working on the problem of evaluating detergency, a very difficult problem, and on specifications and methods for dry cleaning and metal detergents.

I. NEW TENTATIVE STANDARDS

The committee recommends that the following six new specifications for soaps and detergents, and a new method of test be accepted for publication as tentative:

Tentative Specifications for:[1]
- Sodium Metasilicate,
- Trisodium Phosphate,
- Palm Oil Bar Soap,
- Palm Oil Chip Soap,
- Built Soap, Powdered,
- Soap Powder, and

Tentative Methods of Sampling and Chemical Analysis of Special Detergents (D 501 - 39 T)[2] (covering new test for determining carbon dioxide in caustic soda by evolution method, and analytical procedures for trisodium phosphate and sodium metasilicate).

II. REVISION OF TENTATIVE STANDARD

The committee recommends that the definitions for alkaline detergents, builder, built soap, and detergents, appearing in the Tentative Definitions of Terms Relating to Soaps and Other Detergents (D 459 - 38 T),[3] be revised and continued as tentative; new definitions for break soap powder, cleaning, scouring, soap powder, soapy alkaline detergent, and washing are also recommended for publication as tentative. The revised and new definitions are appended hereto.[4]

III. REVISIONS OF STANDARDS

The committee recommends for immediate adoption, revisions in the following two specifications, and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society:

Standard Specifications for Caustic Soda (D 456 - 38):[5]

New Section.—Add a new Section 4 to read as follows, renumbering the present Section 4 as Section 5:

4. *Basis of Purchase.*—Caustic soda shall be purchased by net weight.

Standard Specifications for Modified Soda (Sesquicarbonate Type) (D 457 - 38):[5]

New Section.—Add a new Section 4 to read as follows, renumbering the present Section 4 as Section 5:

4. *Basis of Purchase.*—Modified soda (sesquicarbonate type) shall be purchased by net weight.

IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following ten tentative standards be approved for reference to letter ballot of the Society for adoption as standard, with revisions in four specifications and one method of test, as indicated below:

Tentative Methods of Chemical Analysis of Special Detergents (D 501 - 38 T),[6]

Tentative Methods of Test for Particle Size of Soaps and Other Detergents (D 502 - 38 T),[6]

Tentative Methods of Sampling and Chemical Analysis of Soaps and Soap Products (D 460 - 38 T),[6] revised by the addition of procedures for determining rosin and iodine value, and the preparation of fatty matter,[7]

Tentative Definitions of Terms Relating to Soaps and Other Detergents (D 459 - 38 T),[8] excepting the definitions for builder, built soap, detergents, and alkaline detergents, which are being revised and continued as tentative as mentioned earlier in this report,

Tentative Specifications for Milled Toilet Soap (D 455 - 38 T),[9]

Tentative Specifications for White Floating Toilet Soap (D 499 - 38 T),[9]

Tentative Specifications for Ordinary Laundry

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[1] These specifications were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

[2] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1262 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1580.

[4] These definitions were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

[5] 1938 Supplement to Book of A.S.T.M. Standards, pp. 240 and 241.

[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1258, 1236, 1212 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1576, 1554, 1530.

[7] These new procedures were adopted as standard by the Society and have been incorporated in the Standard Methods of Sampling and Chemical Analysis of Soaps and Soap Products (D 460 - 39), 1939 Book of A.S.T.M. Standards, Part III.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1262 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1580.

[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1200 to 1210 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1518 to 1528.

Bar Soap (D 497 – 38 T),[9] revised by the omission of the word "laundry" from the title of the specifications and Sections 1, 2, 3, and 4.

Tentative Specifications for Chip Soap (D 496 – 38 T),[9] revised as follows:

Section 1.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

1. These specifications cover chip soap suitable for [high-grade laundry work] *washing, cleaning, and scouring purposes* with soft water, when the presence of alkaline salts is [objectionable] *not desirable.*

Tentative Specifications for Powdered Laundry Soap (D 498 – 38 T),[9] revised as follows:

Title.—Change the title of these specifications by the omission of the word "Laundry."

Section 1.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

1. These specifications cover powdered soap suitable for [high-grade laundry work] *washing, cleaning, and scouring purposes* with soft water, when the presence of alkaline salts is [objectionable] *not desirable.*

Sections 2, 3, and 4.—Change Section 2 by the omission of the phrase "for laundry use"; change Sections 3 and 4 by the omission in the first sentence of the word "laundry."

Tentative Specifications for Soda Ash (D 458 – 38 T),[8] revised as follows:

New Section.—Add a new Section 6 to read as follows, renumbering the present Section 6 as Section 7:

6. *Basis of Purchase.*—Unless otherwise specified in the contract, soda ash shall be purchased by net weight as packed at the place of manufacture.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 57 members; 40 members returned their ballots, the results being shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Methods of Testing (J. B. Crowe, chairman):

Section A on Soaps (M. L. Sheely, chairman) is recommending the adoption as standard of the Tentative Methods of Sampling and Chemical Analysis of Soaps and Soap Products (D 460 – 38 T) with the addition of new methods for rosin (McNicoll method), and for iodine value of soap fatty acids (Wijs method).

Section B on Sulfonated Detergents (Ralph Hart, chairman) is working on several new methods, and hopes to propose them for publication as tentative next year.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Specifications for Sodium Metasilicate	40	0	0
Specifications for Trisodium Phosphate	40	0	0
Specifications for Palm Oil Bar Soap	39	0	1
Specifications for Palm Oil Chip Soap	39	0	1
Specifications for Built Soap, Powdered	39	0	1
Specifications for Soap Powder	39	0	1
Methods of Sampling and Chemical Analysis of Special Detergents (D 501 – 39 T)	40	0	0
II. REVISION OF TENTATIVE STANDARD			
Definitions of Terms Relating to Soaps and Other Detergents (D 459 – 38 T), four revised and six new definitions	39	1	0
III. REVISIONS OF STANDARDS			
Specifications for Caustic Soda (D 456 – 38), immediate adoption	40	0	0
Specifications for Modified Soda (Sesquicarbonate Type) (D 457 – 38), immediate adoption	40	0	0
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Specifications for Milled Toilet Soap (D 455 – 38 T)	39	0	1
Specifications for Soda Ash (D 458 – 38 T), as revised	40	0	0
Specifications for Chip Soap (D 496 – 38 T), as revised	38	1	1
Specifications for Ordinary Laundry Bar Soap (D 497 – 38 T), as revised	39	0	1
Specifications for Powdered Laundry Soap (D 498 – 38 T), as revised	38	0	1
Specifications for White Floating Toilet Soap (D 499 – 38 T)	39	0	1
Sampling and Chemical Analysis of Soaps and Soap Products (D 460 – 38 T), as revised	39	0	1
Chemical Analysis of Special Detergents (D 501 – 38 T)	40	0	0
Test for Particle Size of Soaps and Other Detergents (D 502 – 38 T)	39	0	1
Definitions of Terms Relating to Soaps and Other Detergents (D 459 – 38 T), 14 definitions	40	0	0

Section C on Dry Cleaning Detergents (G. P. Fulton, chairman) is doing exploratory work and hopes to be able to report definite progress next year.

Section D on Special Detergents (W. H. Koch, chairman) is proposing a more accurate evolution method for determining carbon dioxide in caustic soda, and methods of test for trisodium phosphate and sodium metasilicate for publication as tentative under the title, Tentative Methods of Sampling and Chemical Analysis of Special Detergents (D 501 - 39 T). The section is working on methods for other phosphates and silicates.

Subcommittee II on Specifications (F. W. Smither, chairman):

This subcommittee held two meetings during the year. Its various sections have been very active, as indicated by the following condensed statements:

Section A on Textile Soaps (C. L. Nutting, chairman) is submitting for publication as tentative, new Specifications for Palm Oil Bar Soap, and for Palm Oil Chip Soap. It is now considering the formulation of specifications for low titre soaps, olive oil soap, and potash soaps.

Section B on Built Soaps (Frederick Krassner, chairman) is recommending that the Tentative Specifications for Ordinary Laundry Bar Soap (D 497 - 38 T) be adopted as standard with a minor revision, as indicated earlier in this report. The section is also submitting for publication as tentative, proposed Specifications for Soap Powder, and for Built Soap, Powdered.

Section C on Straight Soaps (Israel Katz, chairman) is recommending the adoption as standard of the Tentative Specifications for Milled Toilet Soap (D 455 - 38 T), for White Floating Toilet Soap (D 499 - 38 T), for Chip Soap (D 496 - 38 T), and for Powdered Laundry Soap (D 498 - 38 T), the latter two with minor revisions.

Section D on Dry Cleaning Detergents (G. P. Fulton, chairman) has done exploratory work on its difficult assignment. It is believed that definite progress will be made during the coming year.

Section E on Sulfonated Detergents (J. B. Crowe, chairman) has completed further cooperative laboratory work for evaluating sulfonated detergents by means of washing standard soiled cotton fabrics, using the launderometer under varying conditions, and subsequent grading of the fabrics. Statistical study is now in progress to correlate the data.

Section F on Special Detergents (C. C. Zeigler, chairman) is recommending the inclusion of a section covering basis of purchase in the Standard Specifications for Caustic Soda (D 456 - 38) and for Modified Soda (Sesquicarbonate Type) (D 457 - 38), and in the Tentative Specifications for Soda Ash (D 458 - 38 T) together with the adoption as standard of the latter. This section is further recommending for publication as tentative, new Specifications for Trisodium Phosphate, and for Sodium Metasilicate.

Section G on Metal Cleaners (J. C. Harris, chairman) has had increased interest shown in its work but is in need of more consumer members. It is now working on a scheme of analytical methods for alkaline mixtures, which were studied at the last meeting of Committee D-12. Also, a proposed Government specification for an aluminum cleaner is being studied. Since chemical analysis yields only a portion of the information needed, the study of performance tests on these materials will be taken up. With these data in hand the section will be in a position to consider the formulation of specifications.

This report has been submitted to letter ballot of the committee which consists of 57 members; 40 members returned their ballots, all of whom have voted affirmatively.

Respectifully submitted on behalf of the committee,

H. P. Trevithick,
Chairman.

B. S. Van Zile,
Secretary.

REPORT OF COMMITTEE D-13

ON

TEXTILE MATERIALS

Committee D-13 on Textile Materials held two meetings during the year: one on October 19 to 21, 1938, in New York City, and the other on March 1 to 3, 1939, in Providence, R. I. The number of members and guests registered was 168 and 119, respectively. The total number present at these two meetings has again set a high record of attendance. A third meeting will be held in June at Atlantic City, N. J., in conjunction with the annual meeting of the Society.

The executive direction of the committee's affairs required four meetings of the officers and two meetings of the Advisory Committee. Of the 28 subcommittees or sections which compose the organization of Committee D-13, 23 held sessions at the fall meeting and 24 at the spring meeting. This, together with the many recommendations regarding standards included herein, indicates that the interest in standardization in the textile field has continued to grow and make further progress.

A Symposium on Spun Rayon and Blended Fibers, and an exhibit of rayon staple fibers and materials made from them, were features of the October meeting. The high light of the March meeting was an appropriate observance of the twenty-fifth anniversary of the organization of the committee. Papers were presented reviewing the history and accomplishments of the committee since its formation, as mentioned later in this report under the activities of Subcommittee B-6 on Papers. Two of the original members, D. E. Douty and H. J. Jaquith, were present and took an active part in the program. Ex-chairman A. E. Jury and W. H. Whitcomb, and chairman H. J. Ball reviewed the important events occurring in their respective terms of office, while the terms of the other three chairmen were summarized by members closely associated with the work of each period.

Committee D-13 records with deep regret the withdrawal from the textile industry of G. E. Hopkins and his consequent resignation from Committee D-13. The committee has benefited greatly from the stimulus which he has given to the preparation of standards for the woolen and worsted industry, and from his constructive suggestions and advice concerning all other phases of the committee's work with which he had contact. The withdrawal of R. H. Adams from membership is also recorded; the committee has conferred on him honorary membership as an expression of appreciation of the valuable and conscientious service he has rendered for the past fourteen years.

The Advisory Committee approved the following changes in subcommittee organization and chairmanships: A new Subcommittee A-8 on Glass Fiber and its Products was organized with Dean Harvey as its general chairman and S. M. Dockerty, secretary, and with sections as follows: Section I on Nomenclature and Definitions, Games Slayter, chairman; Section II on Yarn, Roving and Twine, S. J. Rosch, chairman; Section III on Fabrics, K. N. Mathes, chairman; Section IV on Chemical Tests, A. L. Simison, chairman. A. G. Ashcroft was appointed general chairman of Subcommittee A-3 on Wool and Its Products *vice* G. E. Hopkins, resigned. On account of the work incident to the above appointment A. G. Ashcroft resigned the chairmanship of Section IV on Pile Floor Coverings of Subcommittee A-3 and J. N. Dow was appointed in his place. For a similar reason, Dean Harvey relinquished the chairmanship of Subcommittee B-6 on Papers, and R. H. Brown was selected as the new chairman.

The Advisory Committee also approved the following appointments of representatives of Committee D-13: B. S. Van Zile on Committee D-12 on Soaps and Other Detergents; C. J. Huber at the Federal Trade Commission's trade practice conference for the linen industry on October 25, 1938, in New York City; G. E. Hopkins as American representative on the Federation Lainière Internationale, an international organization with headquarters in France, interested in part in standards for wool. The latter appointment provides a link for the exchange of relevant information between the F.L.I. and Committee D-13. Mr. Hopkins' subsequent resignation left a vacancy which has been filled by the appointment of Edwin Wilkinson.

The Executive Committee of the Society has appointed H. J. Ball to fill out the unexpired term of G. E. Hopkins as a member of that committee.

The survey into the interest of the textile industry in the development of test methods for the evaluation of the effect of textile finishing agents, which was reported as in progress a year ago, has culminated in the first research project sponsored by Committee D-13. L. B. Arnold, Jr., of the E. I. du Pont de Nemours and Co., Inc., was placed in charge of a steering committee which succeeded in securing sufficient financial support for a year's study of the problem. The subscribers to the research fund have turned over the active guidance of the project to a Directing Committee, composed of L. B. Arnold, Jr., chairman, Elizabeth Weirick, and H. J. Ball. Further details and plans are described later in this report under Activities of Subcommittees.

The present membership of Committee D-13 is 210; of whom 91 are classified as producers, 51 as consumers, and 68 as general interest members.

Subsequent to the 1938 annual meeting, Committee D-13 presented to the Society through Committee E-10 on Standards a new Tentative Method of Test for Fiber Length of Wool (D 519-38 T). This method was accepted[1] by Committee E-10 for publication as tentative on August 25, 1938, and appears in the 1938 *Proceedings*.[2]

The recommendations of the committee regarding standards and tentative standards under its jurisdiction are summarized below, together with the analysis of the letter ballot on each item. Comments, where necessary, are made under the Activities of Subcommittees.

I. NEW TENTATIVE STANDARDS

The committee presents for publication as tentative three new methods of test,[3] as follows:

Tentative Methods of:

Testing Rayon Staple,

Testing and Tolerances for Single Jute Yarn, and

Test for Apparent Fluidity of Dispersions of Cellulose Fibers in Cuprammonium Hydroxide.

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[1] In submitting this tentative method to Committee E-10 on Standards, Committee D-13 reported results of the letter ballot vote as follows: Of a total membership of 190, 93 members returned their ballots, of whom 49 voted affirmatively, 0 negatively, and 44 members marked their ballots "not voting."

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1173 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1487.

[3] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

II. REVISIONS OF TENTATIVE STANDARDS

The committee is presenting revisions of the following tentative definitions and two methods of test and recommends that, as revised, they be continued as tentative:

Tentative Definitions and Terms Relating to Textile Materials (D 123 – 38 T), revised as appended hereto,[4]

Tentative Methods of Testing and Tolerances for Rayon (D 258 – 37 T), revised as proposed in the Appendix, and

Tentative Methods of Testing and Tolerances for Woven Tapes (D 259 – 36 T), revised as proposed in the Appendix.

III. REVISIONS OF STANDARDS

The committee recommends for immediate adoption, revisions of the following two methods of test, and accordingly asks for the necessary nine-tenths vote at the annual meeting in order that these revised standards may be referred to letter ballot of the Society:

Standard Methods of Testing and Tolerances for Knit Goods (D 231 – 33),[5] and

Standard Specifications and Methods of Test for Osnaburg Cement Sacks (D 205 – 27).[6]

The committee recommends for publication as tentative, revisions as given in the Appendix, of the following four standards:

Standard Specifications and Methods of Test for Asbestos Yarns (D 299 – 37),

Standard Specifications and Methods of Test for Asbestos Roving for Electrical Purposes (D 375 – 37),

Standard Specifications and Methods of Test for Cotton Goods for Rubber and Pyroxylin Coating (D 334 – 34), and

Standard Methods of Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 – 38).

IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative standards be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of:

Test for Shrinkage in Laundering of Silk and Rayon Woven Broad Goods (D 416 – 35 T), revised as proposed in the Appendix,

Testing Pile Floor Covering (D 418 – 38 T),[7] without revision,

Testing and Tolerances for Certain Carded Cotton Gray Goods (D 433 – 36 T),[8] without revision,

Testing and Tolerances for Yarns Spun from Wool Mixed with Fibers Other than Wool (D 508 – 38 T),[7] without revision,

Test for Fastness of Colored Textile Fabrics to Light (D 506 – 38 T), revised as proposed in the Appendix, and

Testing and Tolerances for Spun Rayon Yarns and Threads (D 507 – 38 T), revised as proposed in the Appendix.

V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

The committee recommends that the tentative revisions[9] of the following three standards which have been published for a year or more be approved for adoption as standard:

Standard General Methods of Testing Woven Textile Fabrics (D 39 – 38; A.S.A. L 5 – 1938), changes in Sections 16 and 17,

Standard Specifications for Textile Testing Machines (D 76 – 37), change in Section 2 (*d*),

Standard Methods of Testing and Tolerances for Cotton Sewing Threads (D 204 – 36).

VI. TENTATIVE STANDARDS AND REVISIONS CONTINUED AS TENTATIVE

The committee recommends that all other tentative standards and tentative revisions of standards under its jurisdiction not specifically mentioned be continued as tentative.

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[4] These definitions were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

[5] These methods were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

[6] These specifications were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1188, 1176 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1506, 1490.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 1143 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 1438.

[9] *Proceedings*, Am. Soc Testing Mats., Vol. 38, Part I, pp. 1333 to 1337 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1699 to 1703.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 210 members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

The activities of those subcommittees and sections which are submitting recommendations affecting standards are summarized below:

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Testing Rayon Staple	48	1	44
Testing and Tolerances for Single Jute Yarn	42	0	51
Test for Apparent Fluidity of Dispersions of Cellulose Fibers in Cuprammonium Hydroxide	39	0	54
II. REVISIONS OF TENTATIVE STANDARDS			
Definitions and Terms Relating to Textile Materials (D 123 - 38 T)	79	0	14
Testing and Tolerances for Rayon (D 258 - 37 T)	50	0	43
Testing and Tolerances for Woven Tapes (D 259 - 36 T)	44	0	49
III. REVISIONS OF STANDARDS			
Testing and Tolerances for Knit Goods (D 231 - 33), immediate adoption	36	0	57
Spec. and Tests for Osnaburg Cement Sacks (D 205 - 27), immediate adoption	31	1	61
Spec. and Tests for Asbestos Yarns (D 299 - 37)	32	0	61
Spec. and Tests for Asbestos Roving for Electrical Purposes (D 375 - 37)	33	0	60
Spec. and Tests for Cotton Goods for Rubber and Pyroxylin Coating (D 334 - 34)	50	2	41
Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 - 38)	44	1	48
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test of Shrinkage in Laundering of Silk and Rayon Woven Broad Goods (D 416 - 35 T), as revised	40	2	51
Testing Pile Floor Coverings (D 418 - 38 T)	36	0	57
Testing and Tolerances for Certain Carded Cotton Gray Goods (D 433 - 36 T)	53	0	40
Testing and Tolerances for Yarns Spun from Wool Mixed with Fibers Other than Wool (D 508 - 38 T)	44	0	49
Test for Fastness of Colored Textile Fabrics to Light (D 506 - 38 T), as revised	57	0	36
Testing and Tolerances for Spun Rayon Yarns and Threads (D 507 - 38 T), as revised	53	0	40
V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Testing Woven Textile Fabrics (D 39 - 38; A.S.A. L 5 - 1938)	68	0	25
Spec. for Textile Testing Machines (D 76 - 37)	68	1	24
Testing and Tolerances for Cotton Sewing Threads (D 204 - 36)	48	1	44

Subcommittee A-1 on Cotton and Its Products (K. B. Cook, chairman):

Section II on Cotton Yarns and Threads (A. C. Clifford, chairman) is recommending the adoption of the tentative revision of the Standard Methods of Testing and Tolerances for Cotton Sewing Threads (D 204 – 36). This revision, which provides a method for determining yardage of thread in a package, has been tentative for one year, during which time no criticisms have been received concerning it.

Section III on Light and Medium Cotton Woven Fabrics (R. T. Fisher, chairman) is recommending tentative revisions of the Standard Specifications and Methods of Test for Cotton Goods for Rubber and Pyroxylin Coating (D 334 – 34). These revisions involve a modification of the total allowable percentages of sizing and natural oils and waxes. The section is also recommending the adoption of the Tentative Methods of Testing and Tolerances for Certain Carded

Cotton Gray Goods (D 433 – 36 T) which have been tentative for three years, during which time no criticisms have been received concerning them.

Section IV on Tire Fabrics (Martin Castricum, chairman) is presenting a revision of the Standard Methods of Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 – 38). This revision provides requirements for the number of tests to be made in the measurement of the physical characteristics of tire cord.

Section V on Heavy Cotton Woven Fabrics (B. L. Whittier, chairman) recommends the continuation of the Standard Specifications for Tolerances for Numbered Cotton Duck (D 230 – 27) in their present form pending a review of the standard looking toward recommending any desirable changes.

Section VI on Narrow Fabrics (F. S. Mapes, chairman) is presenting a revision, as given in the Appendix, of the Tentative Methods of Testing and Tolerances for Woven Tapes (D 259 – 36 T). This revision provides for a change in the type of gage used for the measurement of thickness, and editorial changes in the requirements for the apparatus and method for the determination of acidity.

Subcommittee A-2 on Rayon and Its Products (A. M. Tenney, chairman):

Section I on Rayon (A. M. Tenney, chairman) is presenting a revision, as given in the Appendix, of the Tentative Methods of Testing and Tolerances for Rayon (D 258 – 37 T). This revision provides for the elimination of requirements for spun rayon which now appear in separate standards, certain changes in tolerances, and making the single strand method the preferred method for tensile strength determination.

Section II on Rayon Fabrics (Alexis Sommaripa, chairman) is recommending the adoption of the Tentative Method of Test for Shrinkage in Laundering of Silk and Rayon Woven Broad Goods (D 416 – 35 T) revised as given in the Appendix. This section is retaining the Tentative Method of Test for Resistance to Yarn Slippage in Silk, Rayon, and Silk-Rayon Woven Broad Goods (D 434 – 36 T) as tentative since the method is now being studied with a view to its improvement.

Section III on Rayon Staple and Spun Rayon Yarn (K. B. Cook, chairman) is presenting for publication, new Tentative Methods of Testing Rayon Staple.[3] These methods were developed in response to an imperative demand for standard methods of testing, arising from the extensive use of rayon staple.

The section is recommending the adoption of the Tentative General Methods of Testing and Tolerances for Spun Rayon Yarns and Threads (D 507 – 38 T), revised editorially as given in the Appendix.

Subcommittee A-3 on Wool and Its Products (A. G. Ashcroft, chairman):

Section III on Woolen and Worsted Yarns (Fred Noechel, chairman) is recommending the adoption of the Tentative Methods of Testing and Tolerances for Yarns Spun from Wool Mixed with Fibers Other than Wool (D 508 – 38 T) no criticisms having been received of these methods.

Section IV on Pile Floor Coverings (J. N. Dow, chairman) is recommending the adoption of the Tentative Methods of Testing Pile Floor Coverings (D 418 – 38 T), no criticisms having been received of these methods.

Subcommittee A-4 on Asbestos and Its Textile Products (F. S. Mapes, chairman):

This subcommittee is recommending for publication tentative revisions, as given in the Appendix, of the Standard Specifications and Methods of Test for Asbestos Yarns (D 299 - 37) and for Asbestos Roving for Electrical Purposes (D 375 - 37). These revisions provide a clarification of the wording and a distinction between metallic and reinforced yarns in methods of determining asbestos content and yards per pound.

Subcommittee A-5 on Bast and Leaf Fibers and Their Products (A. R. Howe, chairman):

To meet a long-standing need for standard test methods, this subcommittee is presenting for publication, new Tentative Methods of Testing and Tolerances for Single Jute Yarn.[3]

The subcommittee is studying the Standard Specifications and Methods of Test for Cuban (Jute) Raw Suger Bags (D 275 - 33), but is not ready to make any definite recommendations regarding a revision of this standard.

Subcommittee B-1 on Methods and Machines (W. D. Appel, chairman):

Section I on Methods (W. D. Appel, chairman) is recommending the adoption of the tentative revisions of the Standard General Methods of Testing Woven Textile Fabrics (D 39 - 38; A.S.A. L5 - 1938) which provide for a method of determining the bow and the twist of yarns in fabrics; the revision of the raveled strip method is being continued as tentative for another year.

The section is also recommending for immediate adoption a revision[5] of the Standard Methods of Testing and Tolerances for Knit Goods (D 231 - 33) which will bring the standard into accord with present practice.

Section II on Machines (H. J. Ball, chairman) is recommending the adoption of the revision, which has been published as tentative for a year, of Section 2 (*d*) of the Standard Specifications for Textile Testing Machines (D 76 - 37), no criticisms having been received of this method of calibrating vertical testing machines. The revision which specifies requirements for testers for determining bursting strength is being retained as tentative for another year.

Subcommittee B-2 on Nomenclature and Definitions (A. G. Scroggie, chairman):

This subcommittee is presenting for publication a revision of the Tentative Definitions and Terms Relating to Textile Materials (D 123 - 38 T). The revision includes the addition of new definitions, changes in certain existing definitions, and the transfer of certain definitions to D 123 from the Glossary of Terms.[10] Additional definitions are being presented for publication in the Glossary.

Subcommittee B-4 on Bleaching, Dyeing and Finishing (W. M. Scott, chairman):

This subcommittee is presenting for publication, a new Tentative Method of Test for Apparent Fluidity of Dispersions of Cellulose Fibers in Cuprammonium Hydroxide[3] which provides a standard test for measuring the degradation of cellulose in finishing operations.

The subcommittee also recommends the adoption of the Tentative Method of Test for Fastness of Colored Textile Fabrics to Light (D 506 - 38 T), revised as given in the Appendix. The revisions provide for the use of a standard sample of a particular material for rating fastness to light when specified rather than reference to standard dyeings.

Subcommittee B-6 on Papers (R. H. Brown, chairman):

This subcommittee arranged for a Symposium on Spun Rayon and Blended

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[10] Compilation of "A.S.T.M. Standards on Textile Materials," p. 259, October, 1938, available as a separate publication.

Fibers at the October, 1938, meeting. The following papers were presented:

> "Rayon Staple Manufacture," by Frederic Bonnet,
> "Test Methods," by H. DeW. Smith,
> "Processing of Spun Rayon and Spun Rayon Mixtures," by W. H. Cady,
> "Fabrication, Merchandising and Construction of Spun Rayon and Blended Fabrics," by Alexis Sommaripa, and
> "The Economic Significance of Rayon Staple Fiber—A Few Observations on the Industry Here and Abroad," by S. B. Hunt.

The subcommittee also arranged for the presentation of the following papers at the Twenty-fifth Anniversary Meeting held in March, 1939:

> "History of Committee D-13," by H. J. Jaquith,
> "Committee D-13 and the Textile Industry,"[11] by H. J. Ball, and
> "Some Important Phenomena in Moisture Adsorption," by E. K. Strachan.

Abstracts of the above papers are being prepared for publication in the 1939 edition of the compilation of "A.S.T.M. Standards on Textile Materials."

Special Committee for Testing of Textile Finishes (L. B. Arnold, Jr., chairman):

The Special Committee for Testing of Textile Finishes was organized under the sponsorship of Committee D-13 as a cooperative research project for the purpose of developing physical test methods for textile finishes. Its funds have been obtained from subscriptions by interested firms. These are paid to the treasurer of the Society and payments are made from the fund upon proper authorization by the Directing Committee.

The membership of the committee comprises the subscribers to its research fund, W. D. Appel and K. H. Barnard in an advisory capacity, and H. J. Ball as chairman of Committee D-13.

The research work will be done by a research associate employed by the committee and working at the National Bureau of Standards in the Textile Section under the immediate guidance of W. D. Appel. The types of finishes for which it is proposed to develop test methods are softened finishes, crease-resistant finishes, slip-proofed finishes, shrink-proofed finishes, and flame-proofed finishes.

This report has been submitted to letter ballot of the committee which consists of 210 members; 93 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. J. BALL,
Chairman.

W. H. WHITCOMB,
Secretary.

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[11] ASTM BULLETIN, No. 98, May, 1939, p. 19.

APPENDIX

PROPOSED REVISIONS IN STANDARDS FOR TEXTILE MATERIALS

In this Appendix are given proposed revisions in certain standards and tentative standards covering textile materials which are referred to earlier in this report. In connection with each title is given the reference to the publication in which the standard appears in its present form.

Revisions of Tentative Standards

Tentative Methods of Testing and Tolerances for Rayon (D 258 - 37 T):[1]

Title.—Change the title to read as follows by the addition of the italicized words:

Tentative Methods of Testing and Tolerances for *Continuous Filament* Rayon *Yarns*.

Section 1.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

1. These methods of testing and tolerances apply to the various types of rayon *yarns* in the form of *continuous* filaments [or yarn].

Section 2 (c).—Delete this paragraph which defines spun rayon.

Section 5.—Change from its present form: namely,

5. The denier of a rayon yarn is numerically equal to the weight in grams of 9000 m.

to read as follows:

5. The denier of a rayon yarn is the number of unit weights of 0.05 g. per 450-m. length.

NOTE 1.—Denier is equal numerically to the number of grams per 9000 m.

NOTE 2.—The "New International Denier" is equal numerically to the number of grams per 10,000 m.

Section 6.—Delete this section which defines spun rayon yarns, renumbering the subsequent sections accordingly.

Section 8.—Change the tolerances in Paragraphs (*a*) and (*b*) to read as follows by the addition of the italicized figures and the omission of the figures in brackets:

[10] *8* per cent for denier finer than 150, and
[8] *6* per cent for 150 denier or coarser.

[5] *4* per cent for denier finer than 150, and
[4] *3* per cent for 150 denier or coarser.

Section 9.—Delete this section which gives tolerances for spun rayon yarn, renumbering the subsequent sections accordingly.

Section 11.—Change the permissible variations in twist to read as follows by the addition of the italicized words and figures and the omission of those in brackets:

Turns per Inch	Permissible Variations
Under $7\frac{1}{2}$	±[25] *20* per cent
$7\frac{1}{2}$ to 10	±[15] *10* per cent
[over] 10 *and over*	± 5 per cent

Section 16.—Change the last sentence from its present form: namely,

Mounting medium, either methylene iodide or monobrom naphthalene.

to read as follows:

Mounting media: For regenerated cellulose rayons, either colorless mineral oil (refractive index 1.46) or monobromnapthalene (refractive index 1.66); for acetate rayon, decane (refractive index 1.41).

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 1202 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 1449.

Section 26 (a).—Change the last sentence of this section to read as follows by the addition of the italicized figures and the omission of those in brackets:

> A tolerance of plus or minus 2 per cent is permitted in relative humidity and [plus 10 F. (6 C.)] *plus or minus 2 F. (1.1 C.)* in temperature.

Sections 25 to 29.—Renumber as Sections 26 to 30 and designate the method for strength as the "Alternate Method."

Sections 30 to 32.—Renumber as Sections 23 to 25 and designate the method for strength as the "Preferred Method."

Tentative Methods of Testing and Tolerances for Woven Tapes (D 259 – 36 T):[2]

Section 8.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

> 8. The thickness of the tape shall be determined in accordance with [Method B of the Tentative Methods of Test for Thickness of Solid Electrical Insulation (A.S.T.M. Designation: D 374 – 36 T)] *the Standard General Methods of Testing Woven Textile Fabrics (A.S.T.M. Designation: D 39)* of the American Society for Testing Materials.

Section 20.—Change the first sentence in Paragraph (*a*) to read as follows by the addition of the italicized word and the omission of the word in brackets:

> The determination of acidity or alkalinity of tapes shall be determined on any standard commercial quinhydrone pH indicator having a sensitivity and [accuracy] *readibility* of 0.02 pH.

Change the first sentence of Paragraph (*c*) to read as follows by the addition of the italicized words:

> A stock solution of potassium chloride shall be prepared by adding *special* c.p. potassium chloride, *free from bromate*, to hot distilled water until saturated and the solution allowed to cool.

Add as a new paragraph (*d*) a description of the quinhydrone used to read as follows, relettering the subsequent paragraphs accordingly:

> (*d*) The quinhydrone used in the test shall have a quinone content within the limits of 49 to 51 per cent of the total weight.

Change Paragraph (*j*) of this section to read as follows by the addition of the italicized word and the omission of the word in brackets:

> (*j*) The potentiometer shall be [sensitive] *readable* to at least 0.001 v.

Section 21.—Change the first sentence of Paragraph (*b*) to read as follows by the addition of the italicized words:

> The solution for the acidity test shall be prepared by placing a 10-g. sample of the tape *cut into pieces $\frac{1}{4}$ in. square* in a Soxhlet extractor and adding sufficient water to cover it.

Change Paragraph (*c*) of this section from its present form to read as follows:

> (*c*) The potassium chloride–calomel electrode shall be inserted into the prepared test solution (Paragraph (*b*)) so that the end of the electrode extends well below the level of the solution. The platinum or gold electrode shall be inserted into the solution at the opposite side of the calomel electrode. It shall be so placed that the gold or platinum of the electrode is well below the level of the solution. Solid quinhydrone shall be added to the test sample until no more will dissolve. Since quinhydrone is not very soluble, only a small amount will be required. The electrodes, potentiometer, galvanometer, Weston or similar standard cell, and the 2-v. battery shall be connected so as to measure the voltage between the electrodes (Fig. 2). The potentiometer and temperature readings shall be taken 2 min. after the immersion of the electrodes in the sample. The pH value shall be determined from standard tables. During the whole procedure care shall be taken to prevent contamination of the test solution by gases which may be present in the surrounding atmosphere. Duplicate tests shall be made on composite samples of the tape and the pH value reported for each sample.

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[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 1147 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 1442.

Tentative Revisions of Standards

Standard Specifications and Methods of Test for Asbestos Roving for Electrical Purposes (D 375 – 37):[3]

Section 6.—Add a new Paragraph (*b*) to read as follows:

(*b*) The cut of reinforced asbestos roving shall be determined without removing the reinforcing core yarn.

Standard Specifications and Methods of Test for Asbestos Yarns (D 299 – 37):[3]

Section 3.—Change this section from its present form to read as follows:

3. (*a*) The standard number of asbestos yarn is designated as "cut." The yards per pound of the standard cuts shall conform to the following:

Cut Designation	Nominal Yards per Pound	Permissible Variations in Average Yards per Pound	Permissible Variations in Yards per Pound in Single Skein
5-cut	500	450 to 549	400 to 599
6-cut	600	550 to 649	500 to 699
7-cut	700	650 to 749	600 to 799
8-cut	800	750 to 849	700 to 899
9-cut	900	850 to 949	800 to 999
10-cut	1000	950 to 1049	900 to 1099
12-cut	1200	1150 to 1249	1100 to 1299
14-cut	1400	1300 to 1499	1200 to 1599
16-cut	1600	1500 to 1699	1400 to 1799
18-cut	1800	1700 to 1899	1600 to 1999
20-cut	2000	1900 to 2099	1800 to 2199
22-cut	2200	2100 to 2299	2000 to 2399
24-cut	2400	2300 to 2499	2200 to 2599
26-cut	2600	2500 to 2699	2400 to 2799
28-cut	2800	2700 to 2899	2600 to 2999
30-cut	3000	2900 to 3099	2800 to 3199
35-cut	3500	3300 to 3699	3100 to 3899

(*b*) The cut of reinforced asbestos yarn shall be determined without removing the reinforcing yarn.

(*c*) The nominal yardage per pound of plied asbestos yarn shall be determined in the following manner: Divide the nominal single yarn yardage per pound by the number of plies and then reduce the yardage so obtained by 10 per cent to correct for contraction caused by twisting.

(*d*) The yards per pound of metallic asbestos yarn is less than that of plain yarn of the same cut in proportion to the weight of the inserted wire.

(*e*) The yards per pound of sized yarn, single or plied, shall be subject to an additional tolerance of minus 2 per cent in comparison with the corresponding untreated yarn.

Tentative revision, submitted June, 1939.

Section 5 (*b*).—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

(*b*) The asbestos content of [metallic and of] reinforced asbestos [yarns] *yarn* shall be determined [after the wire and reinforcing strands have been removed from the samples] *without removing the reinforcing core yarn.*

New Paragraph.—Add a new paragraph (*c*) to read as follows:

(*c*) The asbestos content of metallic asbestos yarn shall be determined after the wire has been removed.

Tentative revision, submitted June, 1939.

Section 8.—Change to read as follows by the addition of the italicized words:

8. The cut of plain *or reinforced* asbestos yarn, single or plied, shall be calculated by dividing by 100 the yards per pound as determined in accordance with Section 9.

Tentative revision, submitted June, 1939.

Section 9.—Change the first sentence of Paragraph (*a*) to read as follows by the addition of the italicized words and the omission of those in brackets:

In determining the [cut] *yards per pound* of single-ply plain *or reinforced* asbestos yarn, there shall be selected from each case of 300 lb. or fraction thereof, twelve 15-yd. skeins not more than three of which shall be from the same tube.

Change the first sentence of Paragraph (*b*) to read as follows by the addition of the italicized words and the omission of those in brackets:

To determine the [cut] *yards per pound* of a single-ply yarn in plied, plain *or reinforced* asbestos yarn, the skeins shall be selected and tested in accordance with Paragraph (*a*).

Change the first sentence of Paragraph (*c*) to read as follows, by the addition of the italicized words and the omission of those in brackets:

To determine the [cut] *yards per pound* of metallic [or of reinforced] asbestos yarn, single or plied, the weight in grams of the wire or reinforcing strands in a 15-yd. skein shall be determined.

Tentative revision, submitted June, 1939.

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[3] 1937 Supplement to Book of A.S.T.M. Standards, pp. 255, 247.

Standard Specifications and Methods of Test for Cotton Goods for Rubber and Pyroxylin Coating (D 334 – 34):[4]

Section 5.—Change the total allowable percentages of sizing and natural oils and waxes for sateens and broken twills, specified in this section, to read as follows, by the addition of the italicized percentages and the omission of those in brackets:

Sheetings	[8.5]	*10.75* per cent
Drills	[11]	*12.0* per cent
Sateens	[10.25]	*12.0* per cent
Broken Twills	[8.15]	*11.25* per cent

Tentative revision, submitted June, 1939.

Standard Methods of Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 – 38):[5]

Section 11.—Change this section from its present form to read as follows:

11. *Number of Tests.*—The number of tests required for the determination of each physical property of tire cord shall be in accordance with Table I which also gives the information on which the requirements are based. The sampling of the shipment shall be as complete or representative as possible within practical limitations.

TABLE I.—NUMBER OF TESTS.

	Breaking Strength	Yards per Pound	Thickness	Twist
Number of tests, *n*	40	10	10	12
Coefficient of variation, *V*, per cent	7	2	2	4
Precision, per cent	3	2	2	3
Probability	0.99	0.99	0.99	0.99

NOTE.—Information available to the committee indicates that the values given in Table I for coefficient of variation, V, are approximately correct, but if the running level of V based on experience is found to be V_1, the number of tests, n_1, required will be determined from the following formula:

$$n_1 = \frac{V_1^2 \times n}{V^2}$$

In no case shall n_1 be less than n.

Tentative revision, submitted June, 1939.

Adoption of Tentative Standards as Standard

Tentative Method of Test for Shrinkage in Laundering of Silk and Rayon Woven Broad Goods (D 416 – 35 T):[6]

Title.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

Tentative Method of Test for *Maximum Residual* Shrinkage [in Laundering] of Silk and Rayon Woven [Broad Goods] *Fabrics.*

Section 1.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

1. This method covers the test procedure for determining the *maximum residual* shrinkage of silk and rayon [woven broad goods] *fabrics* in commercial laundering and for general technical purposes.

Tentative Method of Test for Fastness of Colored Textile Fabrics to Light (D 506 – 38 T):[7]

Section 3.—Designate this section as Paragraph (*a*); change the introductory sentence by the addition of the italicized words, retaining without change the table of wool dyeings and the note; and add a new Paragraph (*b*), as follows:

(*a*) The following standard dyeings on wool shall be used for the classification of light fastness, *unless a standard sample has been provided for the particular material to be tested:*

(*b*) Standard samples, when specified for particular materials, may be used for the classification of light fastness.

Section 6.—Add a new Paragraph (*c*) to read as follows:

(*c*) When a standard sample has been established for a particular material, specimens of the material to be graded shall be tested in comparison with the standard in accordance with Sections 4 and 5 and rated in fastness to light on the following basis:

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[4] 1936 Book of A.S.T.M. Standards, Part II, p. 1295.

[5] 1938 Supplement to Book of A.S.T.M. Standards, p. 227.

[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 1248 (1935); also 1938 Book of A.S.T.M. Tentative Standards, p. 1472.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1163, 1166 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1423, 1465.

Satisfactory.—Specimens which show no greater change in color than the standard.

Unsatisfactory.—Specimens which show a greater change in color than the standard.

Tentative General Methods of Testing and Tolerances for Spun Rayon Yarns and Threads (D 507 – 38 T):[7]

Section 2.—Change this section to read as follows by the addition of the italicized words:

> 2. *Spun rayon is* yarn spun from rayon staple *or cut rayon waste.*

Section 6.—Change the title of this section from its present form: namely, "Standard Regain" to read as follows: "Commercial Regain."

REPORT OF COMMITTEE D-17

ON

NAVAL STORES

A meeting of Committee D-17 on Naval Stores was held in Baltimore, Md., on April 5, 1939.

A revision of the Tentative Method of Test for Softening Point by Tapered Ring Apparatus (E 28 – 36 T) with regard to title, use of hot plate in melting sample, and optional use of ball guide has been recommended by Technical Committee II of Committee E-1 on Methods of Testing. Committee D-17 is represented on this technical committee by C. E. Kinney. In order that Mr. Kinney's vote would represent the wishes of Committee D-17 the proposed revisions were referred to letter ballot of the committee which consists of 21 members; 21 members returned their ballots, all of whom have voted affirmatively.

The necessity for further revision of Method E 28 so as to permit the optional use of a shouldered ring for certain high-melting point resins and modified rosins and, for resins which evolve gas on fusion, to permit the presence of bubbles in the sample after pouring into ring, is now under consideration.

Several editorial improvements have been made in the Standard Method of Test for Determination of Toluol Insoluble Matter in Rosin (D 269 – 30) as a result of review of this test which has been standard for over six years without revision.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Softening Point of Rosin (C. E. Kinney, chairman).—One meeting of this subcommittee was held during the year: in Washington, D. C., on March 2, 1939. The committee has proceeded with its plans and submitted six samples to each of its eight members for determinations of softening point by the Tentative Method of Test for Softening Point by Tapered Ring Apparatus (E 28 – 36 T), using a shouldered ring as well as the tapered ring. Reports from five collaborators show excellent agreement on all except one sample. On this sample the results of four collaborators were in close agreement. While the average softening points obtained with the shouldered ring were slightly higher than with the tapered ring, the differences were so small that the rings may be used interchangeably. Further conclusions cannot be made until results are obtained from the remaining collaborators.

Subcommittee II on Crystallization (E. V. Romaine, chairman).—One meeting of this subcommittee was held during the year: in Wilmington, Del., on January 17, 1939. The present objective of the subcommittee is to standardize the low-temperature heat-treatment method for determining the crystallizing tendency of rosin. Three samples of wood rosin and two samples of gum rosin were submitted to each member for test by this method. The presentation of results will await completion of work by the collaborators.

Subcommittee IV on Acid and Saponification Numbers and Unsaponifiable Matter (C. C. Zeigler, chairman).—This subcommittee has before it the following two projects: (1) Rechecking saponification values on samples of rosin, and (2) a study of the determination of unsaponifiable matter in rosin.

In 1937 the subcommittee studied methods for the determination of acid value and saponification value on rosin. This work resulted in the publication of tentative methods for both of these determinations (D 464 – 37 T and D 465 – 37 T). It was decided at that time, however, that the work on saponification value would be checked on a new series of cooperative samples before the methods were recommended for adoption as standard. Three samples of rosin were sent to the members of the subcommittee for analysis. Complete results, however, are not available, so that compilations cannot be made at this time.

A study of the method for the determination of unsaponifiable matter is being continued by a small subgroup of the committee.

Subcommittee V on Darkening and Volatile Matter upon Heating (R. J. Sobatzki, chairman).—No cooperative work was undertaken by this subcommittee during the year. The chairman, however, made an investigation of the darkening of rosin on heating and was unable to find a laboratory method which would give results that could be translated to plant practice. His laboratory has developed a method for determining the volatile matter in rosin which gives results in close agreement with the previously proposed steam distillation method. The loss on heating under certain specified conditions is determined by weighing. It is planned to subject this method to a series of cooperative tests.

This report has been submitted to letter ballot of the committee which consists of 21 members; 21 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

F. P. VEITCH,
Chairman.

C. F. SPEH,
Secretary.

REPORT OF COMMITTEE D-18

ON

SOILS FOR ENGINEERING PURPOSES

Committee D-18 on Soils for Engineering Purposes has held three meetings during the past year: in Atlantic City, N. J., on June 29, 1938, in Washington, D. C., on November 29, 1938, and in Columbus, Ohio, on March 7, 1939.

This committee is sponsoring a Symposium on Shear Testing of Soils to be held at this annual meeting of the Society. F. J. Converse and G. P. Tschebotareff are supervising the program. The symposium is presented in order to bring before the engineering profession the most recent developments in this phase of soil mechanics, and to provide those interested in the problem with an opportunity to discuss and coordinate their ideas. The problem of determining the shearing resistance of soils is a perplexing one. Probably no other physical characteristic has received more intensive study by those interested in understanding the fundamental mechanics of the action of soil under load. Those who have studied the subject most extensively recognize that different types of equipment and different procedures result in different values of shearing resistance in some types of soil. During the past few years interest in the subject has broadened, and many laboratories are working on the problem. Much excellent work has been done and it is important that the various points of view and lines of endeavor be brought together and discussed in order that further advances may proceed along sound lines. The papers comprising the symposium are as follows:

"Torsional Shear Tests and Their Place in the Determination of the Shearing Resistance of Soils," by M. Juul Hvorslev,

"Some Practical Aspects of Soil Shear Testing," by Gregory P. Tschebotareff,

"Essential Features of Triaxial Shear Tests," by C. A. Hogentogler and E. S. Barber,

"Studies of Critical Void Ratio and Shearing Resistance of Cohesionless Soils by Means of a Triaxial Compression Machine," by John D. Watson,

"A Comparison of Results of Direct Shear and Cylindrical Compression Tests," by Donald W. Taylor, and

"Shearing Resistance of Soil—Its Measurement and Practical Significance," by W. S. Housel.

ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following seven tentative methods[1] of test be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of:

Preparing Soil Samples as Received from the Field for Mechanical Analysis and the Determination of the Subgrade Soil Constants (D 421 - 38 T),

Mechanical Analysis of Soils (D 422 - 38 T),

Test for Liquid Limit of Soils (D 423 - 38 T),

Test for Plastic Limit and Plasticity Index of Soils (D 424 - 38 T),

Test for Centrifuge Moisture-Equivalent of Soils (D 425 - 38 T),

Test for Field Moisture Equivalent of Soils (D 426 - 38 T), and

Test for Shrinkage Factors of Soils (D 427 - 38 T).

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 942 to 968 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 947 to 973.

These recommendations have been submitted to letter ballot of the committee which consists of 70 members; 58 members returned their ballots, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee III on Methods of Sampling Soils (R. R. Litehiser, chairman) is now studying the Tentative Methods of Surveying and Sampling Soils for Use in Place as Subgrades for Highways (D 420 – 35 T). It is expected that a revision of these methods will be presented for action at the next meeting of the committee for submission to the Society during the summer through Committee E-10 on Standards.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Method of Preparing Soil Samples as Received from the Field for Mechanical Analysis and the Determination of the Subgrade Soil Constants (D 421 – 38 T)	48	4	6
Method of Mechanical Analysis of Soils (D 422 – 38 T)[a]	42	11	5
Test for Liquid Limit of Soils (D 423 – 38 T)[b]	46	6	6
Test for Plastic Limit and Plasticity Index of Soils (D 424 – 38 T)	51	2	5
Test for Centrifuge Moisture Equivalent of Soils (D 425 – 38 T)	45	1	12
Test for Field Moisture Equivalent of Soils (D 426 – 38 T)	47	2	9
Test for Shrinkage Factors of Soils (D 427 – 38 T)	47	4	7

[a] The classified vote on the adoption of the Tentative Method of Mechanical Analysis of Soils (D 422 – 38 T) was as follows: Affirmative: 13 producers, 15 consumers, 14 general interests; negative: 2 producers, 5 consumers, 4 general interests.

[b] The classified vote on the adoption of the Tentative Method of Test for Liquid Limit of Soils (D 423 – 38 T) was as follows: Affirmative: 12 producers, 18 consumers, 16 general interests; negative: 2 producers, 2 consumers, 2 general interests.

Subcommittee IV on Methods of Testing the Physical Characteristics of Soils (C. A. Hogentogler, chairman) is recommending the withdrawal of the Standard Method of Test for the Determination of Moisture Equivalent of Subgrade Soils in the Field (D 220 – 29), since this method is to be superseded by the adoption of the Tentative Method of Test for Field Moisture Equivalent of Soils (D 426 – 38 T).

Subcommittee V on Methods of Testing for Stabilized Soils (F. C. Lang, chairman) has developed methods of testing soil-cement mixtures and a method of stabilization of soils with emulsified asphalt. It is expected that these methods will be acted on by the committee at its next meeting for presentation to the Society during the summer through Committee E-10 on Standards. These four methods, the titles of which are given below, are appended[2] to this report as information:

Proposed Methods of Test for:

Moisture-Density Relations of Soil-Cement Mixtures,

Durability of Compacted Soil-Cement Mixtures by Repeated Freezing and Thawing,

Durability of Compacted Soil-Cement Mixtures by Repeated Wetting and Drying, and

Stabilization of Soils with Emulsified Asphalt.

This report has been submitted to letter ballot of the committee which consists of 70 members; 58 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. F. CLEMMER,
Chairman.

W. R. NELSON,
Secretary.

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[2] See pp. 498, 501, 504, 507.

APPENDIX I

PROPOSED METHOD OF TEST FOR MOISTURE-DENSITY RELATIONS OF SOIL-CEMENT MIXTURES[1]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the Society, 260 S. Broad St., Philadelphia, Pa.

Scope

1. This method of test is intended for determining the relationship between the moisture content of soil-cement mixtures and resulting densities (oven-dry weight per cubic foot) when the soil-cement mixture is compacted in the laboratory, before cement hydration, as specified herein.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Mold.*—A cylindrical metal mold having a capacity of $\frac{1}{30}$ cu. ft. with an internal diameter of 4.0 in. and a height of approximately 4.6 in., which has a detachable collar assembly approximately 2½ in. in height, to permit preparing compacted specimens of soil-cement mixtures 4.0 in. in diameter and approximately 4.6 in. in height which have a volume of $\frac{1}{30}$ cu. ft. The mold and collar shall be fastened to a detachable base. (See Fig. 1.)

(*b*) *Rammer.*—A metal rammer having a 2-in. diameter circular face and weighing 5.5 lb. The rammer shall be equipped with a suitable arrangement to control the specified drop.

(*c*) *Sleeve.*—Closed cylindrical sleeve slightly less than 4.0 in. in diameter or similar device for removing compacted specimens from the mold.

(*d*) *Balances.*—A balance or scale of 25-lb. capacity sensitive to 0.01 lb.; and a 100-g. capacity balance sensitive to 0.1 g.

(*e*) *Drying Oven.*—A thermostatically controlled drying oven capable of maintaining temperatures of about 110 C. (230 F.) for drying moisture samples.

Procedure

3. (*a*) The air-dry soil first shall be pulverized to pass a No. 4 (4760-micron) sieve so as to separate the soil particles without reducing the particle size. The required cement shall be added to the pulverized soil. The test shall be performed only on that portion of the soil-cement mixture which will pass a No. 4 (4760-micron) sieve. The thoroughly mixed soil-cement sample shall be immediately compacted in the mold in three equal layers, to give a total compacted depth of about 5 in.; each layer being compacted by 25 blows of the rammer dropping free from a height of 12 in. above the elevation of each finally compacted layer. During compaction, the mold shall rest on a uniform, rigid foundation. The blows shall be

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[1] Under the standardization procedure of the Society, this proposed method is under the jurisdiction of the A.S.T.M. Committee D-18 on Soils for Engineering Purposes.

uniformly distributed over the surface of the layer being compacted. After compacting, the collar shall be removed and the top carefully trimmed to the exact height of the mold with a steel straightedge to produce a specimen approximately 4.6 in. in height and having a volume of $\frac{1}{30}$ cu. ft.

(*c*) The weight of the compacted soil-cement mixture shall be determined, the material removed from the cylinder, sliced vertically in the center and a 100-g. sample taken from the center, weighed immediately, dried in an oven at 110 C. (230 F.) for at least 12 hr. or to constant weight. This procedure establishes the moisture-density relation of the air-dry soil-cement mixture.

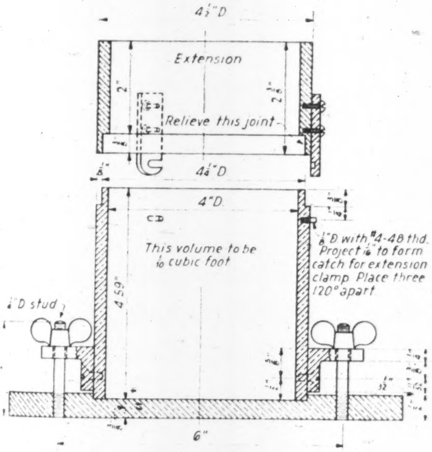
4½" D
Extension
2"
2⅛"
Relieve this joint
4¼" D
⅛"
4" D
This volume to be $\frac{1}{30}$ cubic foot
⅛" D with #4-48 thd. Project $\frac{1}{16}$" to form catch for extension clamp. Place three 120° apart
¼" D stud
4.59"
6"

FIG. 1.—Cylindrical Mold for Moisture-Density Test.

(*d*) The soil-cement mixture shall be again finely pulverized, so as to separate the soil particles without reducing the particle size, to pass a No. 4 (4760-micron) sieve and a small increment of moisture carefully added and thoroughly mixed to insure uniform distribution. Then the moistened and pulverized material shall be compacted in the mold in three layers as described in Paragraph (*a*), weighed, and a moisture determination made to establish the moisture-density relation for a slightly moistened soil-cement mixture. The soil-cement mixture again shall be finely pulverized, so as to separate the soil particles without reducing the particle size, to pass a No. 4 sieve and additional increments of water added and the same procedure followed of mixing, compacting in the mold, weighing, and making moisture determinations until the moisture content of the soil-cement mixture reaches a condition where it is difficult to pulverize the moistened materials, or it has a moisture content near the liquid limit. This procedure will establish the moisture-density relations of a soil-cement mixture for the moisture contents practicable to handle in the field.

Calculation

4. The moisture content and oven-dry weight of the mixture as compacted shall be calculated by means of the following formulas:

$$\text{Moisture, per cent} = \frac{\text{wt. of wet soil-cement} - \text{wt. of oven-dried soil-cement}}{\text{wt. of oven-dried soil-cement}} \times 100$$

$$\text{Dry weight (per cu. ft. of soil-cement as compacted)} = \frac{\text{wet wt. in lb. per cu. ft.}}{\text{percentage of moisture plus 100}} \times 100$$

Moisture-Density Relationship

5. (*a*) The calculations in Section 4 are made to determine the moisture content and corresponding compacted oven-dry weight (density) of the compacted soil-cement for each test made on the mixture. The oven-dry weights per cubic foot (density) of the soil shall be plotted as ordinates and the corresponding moisture contents as abscissas.

(*b*) *Optimum Moisture Content.*—When the moisture-density relations have been determined for a soil-cement mixture and the results plotted as indicated in Paragraph (*a*), it will be found that by connecting the plotted points with a smooth line a curve is produced which is, generally, parabolic in form. The moisture content producing the peak of the curve shall be termed the "optimum moisture content" of the soil-cement mixture under the above compaction.

(*c*) *Maximum Density*.—The oven-dry weight per cubic foot of moist soil-cement mixture at "optimum moisture content" shall be termed "maximum density" under the above compaction.

APPENDIX II

PROPOSED METHOD OF TEST FOR DURABILITY OF COMPACTED SOIL-CEMENT MIXTURES BY REPEATED FREEZING AND THAWING[1]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the Society, 260 S. Broad St., Philadelphia, Pa.

Scope

1. This method of test is intended for determining the durability of soil-cement mixtures of known composition by measuring the soil-cement losses, moisture changes and volume changes (swell and shrinkage) produced by repeated freezing and thawing of specimens of known uniform density and moisture content.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Mold.*—A cylindrical metal mold having a capacity of $\frac{1}{30}$ cu.ft. with an internal diameter of 4.0 in. and a height of approximately 4.6 in., which has a detachable collar assembly $2\frac{1}{2}$ in. in height, to permit preparing compacted specimens of soil-cement mixtures 4.0 in. in diameter and approximately 4.6 in. in height which have a volume of $\frac{1}{30}$ cu.ft. The mold and collar shall be fastened to a detachable base. (See Fig. 1.)[2]

(*b*) *Rammer.*—A metal rammer having a 2-in. diameter circular face and weighing 5.5 lb. The rammer shall be equipped with a suitable arrangement to control the specified drop.

(*c*) *Sleeve.*—Closed cylindrical sleeve slightly less than 4.0 in. in diameter or similar device for removing compacted specimens from the mold.

(*d*) *Balances.*—A balance or scale of 25-lb. capacity sensitive to 0.01 lb.; and a 100-g. capacity balance sensitive to 0.1 g.

(*e*) *Drying Oven.*—A thermostatically controlled drying oven capable of maintaining temperatures of about 110 C. (230 F.) for drying moisture samples.

(*f*) *Freezing Cabinet.*—A freezing cabinet capable of maintaining temperatures of minus 12 C. (10 F.) or lower.

(*g*) *Moist Room.*—A moist room capable of maintaining a temperature of 21 ± 1.7 C. (70 ± 3 F.) and a relative humidity of not less than 90 per cent for seven-day storage of compacted specimens and for thawing frozen specimens.

(*h*) *Wire Scratch Brush.*—A wire scratch brush made of 2-in. by $\frac{1}{16}$-in. flat No. 26 gage wire bristles assembled in 50 groups of 10 bristles each and mounted to form five longitudinal rows and ten transverse rows of bristles on a $7\frac{1}{2}$-in. by $2\frac{1}{2}$-in. hardwood block.

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[1] Under the standardization procedure of the Society, this proposed method is under the jurisdiction of the A.S.T.M. Committee D-18 on Soils for Engineering Purposes.

[2] An illustration of this apparatus appears in Fig. 1 on p. 499.

Preparation of Material for Molding Specimens

3. This test shall be performed on soil-cement mixtures compacted in the mold, before cement hydration, to maximum density at optimum moisture content and in the same manner of compaction as specified in the Proposed Method of Test for Moisture - Density Relations of Soil-Cement Mixtures.[3] Representative roadway soil shall be used except as modified in the following Paragraph (*b*).

(*a*) *For Soil-Cement Mixtures Containing No Material Retained on the No. 4 Sieve.*—A sufficient quantity of each soil-cement mixture to be investigated shall be prepared at optimum moisture content to provide two compacted specimens approximately 4.6 in. in height and 4.0 in. in diameter.

(*b*) *For Soil-Cement Mixtures Containing Material Retained on the No 4 Sieve.*—When the soil-cement mixtures contain material retained on the No. 4 (4760-micron) sieve, the following procedures shall be followed which vary from that described in Paragraph (*a*): Since the specimens are 4 in. in diameter, it is necessary to prescribe the maximum size material to be used in the specimens and this size shall be set at $\frac{3}{4}$ in. Compensation shall be made for any material larger than $\frac{3}{4}$ in. by replacing it with an equal dry weight of No. 4 sieve to $\frac{3}{4}$-in. material of the same gradation as that contained in the original roadway soil sample. A sufficient quantity of minus No. 4 sieve soil-cement material shall be prepared at optimum moisture content to provide two compacted specimens 4.6 in. in height and 4.0 in. in diameter after the requisite amount of saturated surface-moist, plus No. 4 sieve material, as defined above, has been added to the damp, minus No. 4 sieve material.

Molding Specimens

4. (*a*) The prepared material shall be compacted in the mold in the same manner as that specified in the Proposed Method of Test for Moisture - Density Relations of Soil-Cement Mixtures,[3] with the further provision that before placing and compacting the next layer, smooth compaction planes produced during compaction of each layer shall be scarified to form grooves, at right angles to each other, approximately $\frac{1}{8}$ in. in width and $\frac{1}{8}$ in. in depth and approximately $\frac{1}{4}$ in. apart. During compaction, a representative soil-cement mixture moisture sample shall be taken from the batch, weighed, dried in an oven at 110 C. (230 F.) for at least 12 hr. or to constant weight. The compacted specimens shall be removed from the mold, weighed and density determined; the volume shall be determined by (*1*) averaging the diameters measured to the nearest 0.05 cm. at right angles to each other at the center and the quarter points of the specimen and averaging the heights measured to the nearest 0.05 cm. at the quarter points on the circumference of the specimen, or (*2*) by immersion and displacement methods in a nonabsorbent liquid such as mercury.

(*b*) One specimen shall be identified on a metal tag (or other suitable device) as No. 1, together with other needed identification marks and shall be used to obtain data on moisture and volume changes during the durability test. The other specimen shall be identified as No. 2, together with other needed identification marks and shall be used to obtain data on soil-cement losses during the durability test.

(*c*) After the required data have been obtained, the specimens shall be placed on suitable carriers in the moist room and protected from free water for a period of seven days. The No. 1 specimens shall be weighed and measured daily to give data for calculating the moisture content and volume of the specimens each day.

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[3] See p. 498.

Procedure

5. (*a*) At the end of the storage in the moist room, water-saturated felt pads, blotters or similar absorptive material shall be placed between the specimens and the carriers, and the assembly placed in a refrigerator having a constant temperature not warmer than minus 12 C. (plus 10 F.) for 22 hr. and removed. The No. 1 specimen (volume and moisture change specimen) shall be weighed and measured and both specimens placed in the moist room. Free water shall be made available to the absorbent pads under the specimens to permit absorption of water by the specimens by capillarity.

(*b*) After 22 hr. in the moist room, both specimens shall be weighed and the No. 1 specimen measured. Specimen No. 2 (soil-cement loss specimen) shall then be given two firm strokes on all areas with a wire scratch brush to remove all material loosened during freezing and thawing. The specimen shall be again weighed after brushing. The moisture content of the material brushed from the specimen shall be determined directly, but if this is not possible, it may be assumed to be equal to the moisture content of the No. 1 specimen. The oven-dry 110 C. (230 F.) weight of material brushed from the specimen shall be calculated.

(*c*) The procedures described in Paragraphs (*a*) and (*b*) constitute one cycle (48 hr.) of freezing and thawing. The specimens shall then be replaced in the refrigerator and the procedure continued. The data collected will permit calculations of volume and moisture changes of specimen No. 1 and the soil-cement losses of specimen No. 2.

(*d*) The freezing and thawing of the No. 1 specimens shall be continued for 12 cycles or discontinued prior to 12 cycles should the measurements become inaccurate due to distortion or soil-cement loss of the specimen. The freezing and thawing of the No. 2 specimens shall be continued for 12 cycles, if possible.

Calculation

6. The volume and moisture changes and the soil-cement losses of the specimens shall be calculated as follows:

(*a*) The difference between the volume of specimen No. 1 at time of molding and subsequent volumes shall be calculated as a percentage of the original volume.

(*b*) The moisture content of specimen No. 1 at the time of molding and subsequent moisture contents shall be calculated as a percentage of the original oven-dry weight of the specimen.

(*c*) The soil-cement loss of specimen No. 2 shall be calculated as a percentage of the original oven-dry weight of the specimen.

APPENDIX III

PROPOSED METHOD OF TEST FOR DURABILITY OF COMPACTED SOIL-CEMENT MIXTURES BY REPEATED WETTING AND DRYING[1]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the Society, 260 S. Broad St., Philadelphia, Pa.

Scope

1. This method of test is intended for determining the durability of soil-cement mixtures of known composition by measuring the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by repeated wetting and drying of specimens of known uniform density and moisture content.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Mold.*—A cylindrical metal mold having a capacity of $\frac{1}{30}$ cu. ft. with an internal diameter of 4.0 in. and a height of approximately 4.6 in., which has a detachable collar assembly approximately $2\frac{1}{2}$ in. in height, to permit preparing compacted specimens of soil-cement mixtures 4.0 in. in diameter and approximately 4.6 in. in height which have a volume of $\frac{1}{30}$ cu.ft. The mold and collar shall be fastened to a detachable base. (See Fig. 1.)[2]

(*b*) *Rammer.*—A metal rammer having a 2-in. diameter circular face and weighing 5.5 lb. The rammer shall be equipped with a suitable arrangement to control the specified drop.

(*c*) *Sleeve.*—Closed cylindrical sleeve slightly less than 4.0 in. in diameter or similar device for removing compacted specimens from the mold.

(*d*) *Balances.*—A balance or scale of 25-lb. capacity sensitive to 0.01 lb.; and a 100-g. capacity balance sensitive to 0.1 g.

(*e*) *Drying Ovens.*—A thermostatically controlled drying oven capable of maintaining temperatures of about 110 C. (230 F.) for drying moisture samples.

A thermostatically controlled drying oven capable of maintaining temperatures of about 71 C. (160 F.) for drying compacted soil-cement specimens.

(*f*) *Moist Room.*—A moist room capable of maintaining a temperature of 21 ± 1.7 C. (70 ± 3 F.) and a relative humidity of not less than 90 per cent for seven-day storage of compacted specimens.

(*g*) *Water Bath.*—Suitable tank for submerging compacted specimens in water at about 21 C. (70 F.).

(*h*) *Wire Scratch Brush.*—A wire scratch brush made of 2-in. by $\frac{1}{16}$-in. flat No. 26 gage wire bristles assembled in 50 groups of 10 bristles each and mounted to form five longitudinal rows and ten transverse rows of bristles on a 7½-in. by 2½-in. hardwood block.

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[1] Under the standardization procedure of the Society, this proposed method is under the jurisdiction of the A.S.T.M. Committee D-18 on Soils for Engineering Purposes.

[2] An illustration of this apparatus appears in Fig. 1 on p. 499.

Preparation of Material for Molding Specimens

3. This test shall be performed on soil-cement mixtures compacted in the mold, before cement hydration, to maximum density at optimum moisture content and in the same manner of compaction as specified in the Proposed Method of Test for Moisture - Density Relations of Soil-Cement Mixtures.[3] Representative roadway soil shall be used except as modified in the following Paragraph (*b*).

(*a*) *For Soil-Cement Mixtures Containing No Material Retained on the No. 4 Sieve.*—A sufficient quantity of each soil-cement mixture to be investigated shall be prepared at optimum moisture content to provide two compacted specimens approximately 4.6 in. in height and 4.0 in. in diameter.

(*b*) *For Soil-Cement Mixtures Containing Material Retained on the No. 4 Sieve.*—When the soil-cement mixtures contain material retained on the No. 4 (4760-micron) sieve, the following procedures shall be followed which vary from that described in Paragraph (*a*): Since the specimens are 4 in. in diameter, it is necessary to prescribe the maximum size material to be used in the specimen and this size shall be set at ¾ in. Compensation shall be made for any material larger than ¾ in. by replacing it with an equal dry weight of No. 4 sieve to ¾-in. material of the same gradation as that contained in the original soil sample. A sufficient quantity of minus No. 4 sieve soil-cement material shall be prepared at the optimum moisture content to provide two compacted specimens 4.6 in. in height and 4.0 in. in diameter after the requisite amount of saturated, surface-moist, plus No. 4 sieve material, as defined above, has been added to the damp, minus No. 4 material.

Molding Specimens

4. (*a*) The prepared material shall be compacted in the mold in the same manner as that specified in the Proposed Method of Test for Moisture - Density Relations of Soil-Cement Mixtures,[3] with the further provision that before placing and compacting the next layer, smooth compaction planes produced during compaction of each layer shall be scarified to form grooves, at right angles to each other, approximately ⅛ in. in width and ⅛ in. in depth and approximately ¼ in. apart. During compaction, a representative soil-cement mixture moisture sample shall be taken from the batch, weighed, dried in an oven at 110 C. (230 F.) for at least 12 hr. or to constant weight. The compacted specimens shall be removed from the mold, weighed, and the density determined; the volume shall be determined by (*1*) averaging the diameters measured to the nearest 0.05 cm. at right angles to each other at the center and the quarter points of the specimen and averaging the heights measured to the nearest 0.05 cm. at the quarter points on the circumference of the specimen, or (*2*) by immersion and displacement methods in a nonabsorbent liquid such as mercury.

(*b*) One specimen shall be identified on a metal tag (or other suitable device) as No. 1, together with other needed identification marks and shall be used to obtain data on moisture and volume changes during the durability test. The other specimen shall be identified as No. 2, together with other needed identification marks and shall be used to obtain data on soil-cement losses during the durability test.

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[3] See p. 498.

(*c*) After the required data have been obtained, the specimens shall be placed on suitable carriers in the moist room and protected from free water for a period of seven days. The No. 1 specimens shall be weighed and measured daily to give data for calculating the moisture content and volume of the specimens each day.

Procedure

5. (*a*) At the end of the storage in the moist room, the specimens shall be submerged in tap water at room temperature for a period of 5 hr. and removed. The No. 1 specimen (volume and moisture change specimen) shall be weighed and measured.

(*b*) Both specimens shall be placed in an oven at about 71 C. (160 F.) for 42 hr. and removed. Then, both specimens shall be weighed and No. 1 specimen measured. Specimen No. 2 (soil-cement loss specimen) shall then be given two firm strokes on all areas with a wire scratch brush to remove all material loosened during wetting and drying. The specimen shall again be weighed after brushing. The moisture content of the material brushed from the specimen shall be determined directly, but if this is not possible, it may be assumed to be equal to the moisture content of the No. 1 specimen. The oven-dry 110 C. (230 F.) weight of material brushed from the specimen shall be calculated.

(*c*) The procedures described in Paragraphs (*a*) and (*b*) constitute one cycle (48 hr.) of wetting and drying. The specimens shall then be again submerged in water and the procedure continued. The data collected will permit calculations of volume and moisture changes of specimen No. 1 and the soil-cement losses of specimen No. 2.

(*d*) The wetting and drying of the No. 1 specimens shall be continued for 12 cycles or discontinued prior to 12 cycles should the measurements become inaccurate due to distortion or soil-cement loss of the specimens. The wetting and drying of the No. 2 specimens shall be continued for 12 cycles, if possible.

Calculation

6. The volume and moisture changes and the soil-cement losses of the specimens shall be calculated as follows:

(*a*) The difference between the volume of specimen No. 1 at the time of molding and subsequent volumes shall be calculated as a percentage of the original volume.

(*b*) The moisture content of specimen No. 1 at the time of molding and subsequent moisture contents shall be calculated as a percentage of the original oven-dry weight of the specimen.

(*c*) The soil-cement loss of specimen No. 2 shall be calculated as a percentage of the original oven-dry weight of the specimen.

APPENDIX IV

PROPOSED METHOD OF TEST FOR STABILIZATION OF SOILS WITH EMULSIFIED ASPHALT[1]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the Society, 260 S. Broad St., Philadelphia, Pa.

Scope

1. (*a*) This method of test is intended for determining the absorption of soil specimens, and the stability of the same specimens after they have been subjected to the absorption test.

(*b*) The results obtained from this test are used to determine the changes in soil properties produced by stabilization with emulsified asphalt, and to determine the efficiency of stabilization by resistance to plastic flow.

ABSORPTION TEST

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Specimen Molds.*—Molds consisting of seamless brass tubing 2 in. in inside diameter by 5 in. in height for forming the soil specimens.

(*b*) *Tamping Tool.*—A tamping tool made from a steel rod 1 in. in diameter and 8 in. in length with a flat end.

(*c*) *Drying Pans.*—Shallow pans (approximately 2½ by 10 by 15 in.) for holding the wet soil after mixing and until the soil is dried to a proper consistency for molding.

(*d*) *Steel Plunger.*—A steel plunger 1.97 ± 0.01 in. in diameter and 6 in. in length for transmitting pressure to the specimen while the latter is contained within the mold.

(*e*) *Compression Machine.*—A testing machine capable of applying a compressive load of at least 40,000 lb. at uniform rates of from 0.4 to 0.5 in. per min., to be used for applying pressure to the specimen after molding and in subsequent tests.

(*f*) *Sieves.*—A ¼-in. screen or No. 4 round-hole sieve conforming to the Standard Specifications for Sieves for Testing Purposes (A.S.T.M. Designation: E 11) of the American Society for Testing Materials.[2]

(*g*) *Constant Temperature Oven.*—A suitable drying oven, thermostatically controlled at a temperature of 140 ± 3 F. (60 ± 1.6 C.), used for drying the molded soil specimens to constant weight. The oven shall be ventilated and provided with a fan to circulate the air. It may be provided with pans of calcium chloride to lower the humidity and accelerate drying.

(*h*) *Capillary Water Absorption Cabinet.*—A cabinet as shown in Fig. 1 consisting of a covered box-like compartment 7 ft. in length by 2 ft. in width by 13 in. in depth. The cabinet shall be provided with a hinged cover.

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[1] Under the standardization procedure of the Society, this proposed method is under the jurisdiction of the A.S.T.M. Committee D-18 on Soils for Engineering Purposes.

[2] 1939 Book of A.S.T.M. Standards, Parts II and III.

A room in which a constant relative humidity of more than 95 per cent is maintained may be used in lieu of the cabinet. It shall contain a copper pan 1 in. in depth and conforming to the inside floor dimensions of the cabinet. The pan shall be filled level with standard Ottawa sand and covered with heavy cotton flannel. The pan shall be attached to a water-feeding device which shall maintain distilled water in the pan at a constant level of about $\frac{1}{8}$ in. below the cloth.

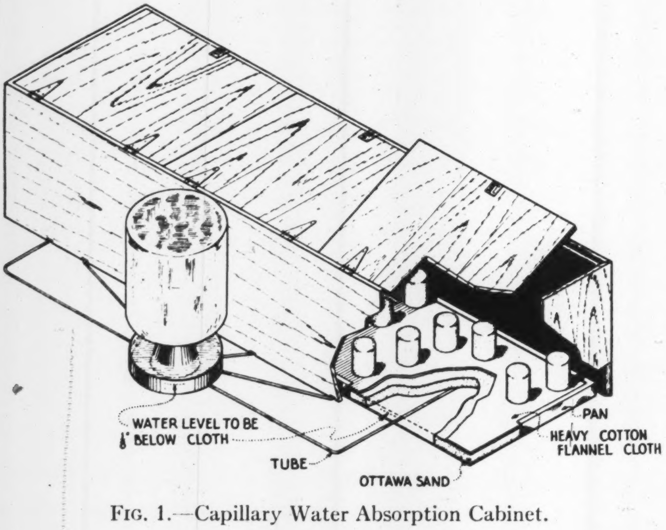

FIG. 1.—Capillary Water Absorption Cabinet.

(*i*) *Balance*.—A balance having a capacity of 500 g., or more, and sensitive to 0.1 g. for weighing the soil specimens.

Test Specimens

3. (*a*) *Preparation of Soil*.—The soil, or aggregate, to be tested, shall be air-dried, aggregations of the soil shall be broken up with a rubber pestle as described in the Standard Method of Preparing Soil Samples (A.S.T.M. Designation: D 421) of the American Society for Testing Materials,[3] and the soil or aggregate shall be thoroughly mixed. It shall then be screened through the $\frac{1}{4}$-in. screen, or the No. 4 sieve, and the percentage passing the sieve shall be noted. Only the material passing the $\frac{1}{4}$-in. screen shall be used in the test, and there shall be at least 500 g. of this material available for each 2 by 4-in. cylinder to be made and tested.

(*b*) *Mixing*.—(1) A 500-g. sample of the soil, or aggregate, passing the $\frac{1}{4}$-in. screen or No. 4 sieve, for each unstabilized specimen to be made, shall then be thoroughly mixed with sufficient water to produce a consistency approximately equal to the consistency represented by the liquid limit of the material being tested.

(2) A 500-g. sample of the soil, or aggregate, passing the $\frac{1}{4}$-in. screen shall be weighed out for each stabilized specimen to be made and tested. Emulsified asphalt diluted with two parts of distilled water shall then be added to soil or aggregate. The quantity of emulsified asphalt to be used in the test shall be determined by the following formula:

$$Q = W\frac{S}{a}$$

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[3] 1939 Book of A.S.T.M. Standards, Part II, p. 451.

where:

Q = weight in grams of undiluted emulsified asphalt to be used,

W = weight in grams of the screened material to be mixed,

S = specified percentage of undiluted emulsified asphalt (based on soil or aggregate before screening), and

a = percentage of soil or aggregate passing the $\frac{1}{4}$-in. screen or No. 4 sieve.

NOTE.—It will be noted that the quantity of emulsified asphalt used is the same as if the material retained on the $\frac{1}{4}$-in. screen or No. 4 sieve had been restored in proper proportion to the screened sample.

Thorough mixing shall be done immediately after the diluted emulsified asphalt has been added to the screened material. Additional water if necessary, shall be added during mixing to insure a uniform distribution of the emulsified asphalt throughout the mixture. (This condition will usually be reached when the consistency of the mix is about that of a soil when wetted to its liquid limit.) The prepared mixtures shall be placed in the shallow pans and allowed to air-dry at room temperature until they shall have reached a consistency approximately equivalent to that obtained in the plastic limit test[3] on the soil or aggregate used.

(c) *Molding and Drying Specimens.*—The plastic mixture shall then be tamped into 2 by 5-in. cylindrical molds in three approximately equal layers until a total compacted depth of 4 in. is obtained. Each layer shall be tamped with 25 strokes of the 1-in. diameter tamping rod. The molded specimens shall then be allowed to further air-dry until they can be compressed under a 3000-lb. load without extruding around the compression plunger. A 3000-lb. load shall then be applied and maintained for 1 min. The specimens shall then be pressed from the mold with the plunger. The molded specimens shall be allowed to air-dry in the laboratory until they have reached a moisture content below which no further apparent shrinkage occurs. The specimens shall then be placed in the drying oven and dried at 140 F. (60 C.) until they reach constant weight.

Procedure

4. The dried soil specimens shall be removed from the drying oven and allowed to cool to room temperature. They shall then be wrapped on the sides and top with moisture-proof cellophane. This wrapping shall be placed so as not to restrict any possible swelling of the test specimens. The specimens shall be weighed to the nearest 0.1 g. and then placed in the capillary absorption cabinet with their lower ends as molded resting on the wet surface of the flannel. The cabinet shall be maintained between 65 and 90 F. (18 and 32 C.) during the test period. At the end of 168 hr. (7 days) the specimens shall be removed from the absorption cabinet and the increase in weight immediately determined.

Calculation

5. The percentage water absorption shall be calculated on the dry weight of the specimen from the following formula:

$$A = \frac{W_2 - W_1}{W_1} \times 100$$

where:

A = percentage of water absorbed during the test period, based on the dry weight of the specimen,

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[3] Standard Method of Test for Plastic Limit and Plasticity Index of Soils (A.S.T.M. Designation: D 424), see 1939 Book of A.S.T.M. Standards, Part II, p. 471.

W_1 = weight of the specimen in grams at the start of the test,

W_2 = weight of the specimen in grams at the completion of the test.

Report

6. The results of the test shall be reported as the average percentage water absorption obtained on the specimens in each set. Each set shall consist of not less than three specimens.

STABILITY TEST

Apparatus

7. The apparatus (see Fig. 2) shall consist of the following:

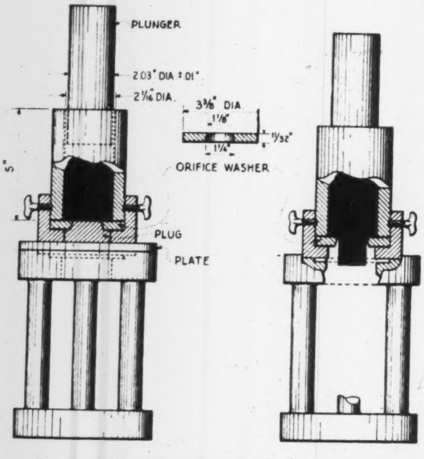

FIG. 2—Stability Testing Cylinder and Support.

(a) *Testing Cylinder.*—A stability testing cylinder $2\frac{1}{16}$ in. in inside diameter, 5 in. in height, having a wall thickness of $\frac{5}{8}$ in., and made of tool steel. The cylinder shall be equipped with a removable case-hardened tool steel orifice plate at the bottom, the orifice having a circular opening exactly 1 sq. in. in area. The aperture shall be tapered outward so as to leave a cutting edge at the face toward the inside of the cylinder. The orifice plate and the cylinder shall be held together by means of wing nuts and screws on a collared base having an inside shoulder which serves as a seat for the orifice plate. A steel plug, tapered so as to entirely close the orifice, shall be provided.

(b) *Testing Cylinder Support.*—A heavy supporting frame designed to support the stability testing cylinder and to withstand the high pressures developed during testing. This frame shall be made by joining two 6-in. diameter circular steel plates, 1 in. in thickness, with three 6-in. lengths of 1-in. diameter steel rod with centers welded at equidistant points along a 5-in. diameter circle. The top end of the frame shall have a series of concentric grooves designed to act as seats, first, for the base of the testing cylinder and second, for the stability testing cylinder. It shall also have a $2\frac{1}{4}$-in. diameter circular hole drilled through the center of the plate to allow passage of the remainder of the specimen after the stability test is completed.

(c) *Steel Plate.*—A steel plate $\frac{1}{4}$ in. in thickness and 6 in. in diameter to serve as an insert between the orifice plug and the top of the supporting stand.

(d) *Steel Plunger.*—A steel plunger having a diameter of 2.03 ± 0.01 in.

(e) *Testing Machine.*—A testing machine as described in Section 2 (*e*).

Test Specimen

8. The test specimens shall consist of the soil or aggregate cylinders prepared and subjected to the absorption test, as described in Sections 3 and 4.

Procedure

9. The test specimens, immediately after they have been subjected to the seven-day absorption test as described in Section 4, shall be placed with the wet ends downward in the testing cylinder. In the event the specimens have swelled to a diameter greater than that

of the testing cylinder, the walls of the specimen shall be carefully scraped until the specimen will snugly fit the testing cylinder. The plug shall then be placed in the orifice and the bottom of the sample pressed firmly into the mold until it shall be in contact with the plate and plug at the bottom. The cylinder shall then be assembled with support and the assembly placed in the compression testing machine. The cylindrical steel plunger shall be placed on the top of the specimen and a load of 3000 lb. shall be applied. The load shall then be immediately released, the supporting plate removed, and the plug left unsupported. The stability test apparatus shall be re-assembled, the cylinder assembly being replaced on the supporting base, with the orifice plate centered over the hole in the supporting stand. Reference marks shall be made on the plunger at $\frac{1}{2}$-in. intervals, spaced from the top of the mold. The load shall then be applied on the plunger at a uniform rate sufficient to move the plunger 0.4 to 0.5 in. per min. As each mark on the descending plunger comes even with the top of the mold, the total indicated load shall be observed and recorded.

Report

8. The stability values shall be reported as the total observed load in pounds at the end of the first $\frac{1}{2}$-in. movement of the plunger. If required, the total load necessary to move the plunger at the end of each successive $\frac{1}{2}$-in. movement may be reported.

REPORT OF COMMITTEE D-19

ON

WATER FOR INDUSTRIAL USES

A meeting of Committee D-19 on Water for Industrial Uses and of each of its subcommittees was held on June 27, 1938, in Atlantic City, N. J., during the annual meeting of the Society.

The committee sponsored a session on water at the 1938 annual meeting at which the following papers[1] were presented:

> "A Method for the Embrittlement Testing of Boiler Waters," by F. G. Straub and T. A. Bradbury,
>
> "Removal of Dissolved Salts from Water by Exchange Filters," by P. G. Bird, and
>
> "The Estimation of Sodium in Water Supplies by an Indirect Method," by J. B. Romer, W. W. Cerna, and H. F. Hannum.

Effective July 1, 1939, H. C. Miller assumes the chairmanship of Subcommittee IV on Methods of Analysis, succeeding J. R. McDermet who has resigned.

The Society has designated Max Hecht as its representative on the Subcommittee on Care of Steam Boilers in Service, functioning under the Boiler Code Committee of the American Society of Mechanical Engineers.

Last year the committee submitted for publication as tentative seven methods covering the sampling and analysis of industrial waters (D 510 - 38 T to D 516 - 38 T, inclusive). Comments and suggestions with respect to these methods are still being received by the committee; the methods will, therefore, be continued as tentative for the present.

RESEARCH ACTIVITIES

Silica in the Presence of Phosphate.—The committee had been informed concerning research on this subject which was carried out for the Gulf State Utilities Co. Through the kindness of E. B. Powell, Consulting Engineer for Stone & Webster Engineering Corp., the following statement by T. E. Crossan, Superintendent of the Gulf State Utilities Co., is reported:

> The latest report by the Gulf State Utilities Co. of research on the colorimetric method for the determination of silica has been issued in the form of a bulletin[2] by the Louisiana State University. The literature on this subject is thoroughly covered in the bulletin; starting from the first published paper, procedures for determining silica colorimetrically are described in considerable detail and include slight revisions over previously published material. The effect of phosphates and the use of permanent standards are also discussed. For details the original should be consulted.

The activities of Subcommittee VIII on Standardization of Water Analysis Methods, of the Joint Research Committee on Boiler Feedwater Studies, with respect to this subject will be furnished in the report of that committee which is to be presented at this annual meeting of the Society.[3]

Research on pH.—The Society's Committee E-9 on Research is still giving consideration to the research program on the subject of pH proposed by the National Bureau of Standards.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, pp. 602 to 646, incl. (1938).

[2] M. C. Schwartz, "Silica in Water," *Bulletin*, Louisiana State University, October, 1938.

[3] Published in ASTM BULLETIN, No. 99, August, 1939, p. 52.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II, Editorial (E. P. Partridge, chairman) held one meeting during the year. No new material has been submitted during the past year for consideration as to editorial arrangement nor have any revisions been suggested with respect to the form of the methods of analysis of industrial waters that were accepted for publication as tentative last year. The activity of this subcommittee has been limited to consideration of the following papers,[4] submitted for presentation at the session on water to be held at this annual meeting of the Society:

"The Calculation of Equilibria in Dilute Water Solutions," by D. S. McKinney,

"The Calculation of the Distribution of Carbon Dioxide Between Water and Steam," by A. M. Amorosi, and J. R. McDermet, and

"Determination by the Evaporation Method of Small Amounts of Dissolved Solids in Water Such as Condensed Steam from Boilers," by R. C. Ulmer.

"Electrical Conductance Measurements of Water Extracts of Textiles," by A. C. Walker.

"The pH, Dissolved Iron Concentration, and Solid Product Resulting from the Reaction Between Iron and Pure Water at Room Temperature," by Richard C. Corey and Thomas J. Finnegan.

Subcommittee III on Methods of Sampling (M. A. Krimmell, chairman) discussed and somewhat reorganized its future work at the meeting held in June, 1938. The main and future objective of this subcommittee is to develop methods of sampling water and steam when removed from equipment pipe lines, etc., at atmospheric, superatmospheric and subatmospheric pressures. At this same meeting a few minor changes were suggested with respect to the Tentative Methods of Sampling Plant or Confined Waters for Industrial Uses (D 510 - 38 T) which will receive further attention at the next meeting of the subcommittee in June, 1939.

Subcommittee IV on Methods of Analysis (J. R. McDermet, chairman) held one meeting during the year. The subcommittee has been receiving comments directed toward a revision of the methods of analysis of industrial waters (D 511 - 38 T to D 516 - 38 T, inclusive) which were accepted for publication as tentative last year.

Work on dissolved oxygen is under way in a section of this subcommittee. Because of the requirements of industry for a satisfactory field method, attention is first being directed toward the preparation of such a method, a draft of which will be presented at the next meeting of the subcommittee. The section is accumulating the results of current experimentation on the determination of dissolved oxygen looking toward the inclusion of this data in a tentative standard.

Subcommittee V on Classification (R. C. Adams, Jr., chairman) held one meeting during the year. The first revision of a preliminary draft of specifications for reporting water analyses will be presented at the next meeting of the subcommittee. It is proposed to express the results of analyses in ionic form, in terms of parts per million by weight, and equivalents per million.

This report has been submitted to letter ballot of the committee, which consists of 57 members; 38 members returned their ballots, of whom 33 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

MAX HECHT,
Chairman.

R. E. HALL,
Secretary.

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[4] See pp. 1191, 1204, 1221, 1233, 1242.

REPORT OF COMMITTEE D-20

ON

PLASTICS

Since the meeting in June, 1938, in Atlantic City, N. J., Committee D-20 on Plastics and its subcommittees have held two meetings: one at the Hotel New Yorker in New York City on November 16, 1938, and one at the Wardman Park Hotel in Washington, D. C., on March 14 and 15, 1939. During the November meeting a joint meeting was held of the advisory committees of Committee D-9 on Electrical Insulating Materials and Committee D-20 for the purpose of discussing the work on plastics being carried on by the two committees, with an idea of avoiding duplication of effort, and on that basis to plan the work for the coming year. It was deemed advisable to hold such a meeting annually.

H. M. Richardson has resigned as chairman of Subcommittee I on Strength Properties and M. H. Bigelow has been appointed in his place.

Committee D-20 now has a membership of 56 voting members, representing an increase of 4 voting members within the year.

The subcommittees of Committee D-20 are considering the following properties of plastics and methods for measuring or testing:

Subcommittee I on Strength Properties (M. H. Bigelow, chairman): compression, tension, and elongation.

Subcommittee II on Hardness Properties (J. C. Pitzer, chairman): scratch or mar resistance, abrasion resistance, and deformation or gradual distortion under load. It is expected that a proposed tentative method of test covering the latter will be available this year.

Subcommittee III on Thermal Properties (L. M. Currie, chairman): flow under molding conditions, changes on heating, and flammability. It is expected that a proposed tentative method of test for flow under molding conditions and a test for measuring the ability of film to extinguish itself will be completed this year.

Subcommittee IV on Optical Properties (H. W. Paine, chairman): haze, surface brightness, reflection factor, surface irregularities, and polarization.

Subcommittee V on Permanence Properties (G. M. Kline, chairman): resistance to light, heat, and moisture.

NEW TENTATIVE STANDARDS

The committee recommends that the two methods of test[1] listed below be accepted for publication as tentative:

Tentative Methods of Test for:

Index of Refraction of Transparent Organic Plastics, and

Resistance of Plastics to Chemical Reagents.

There has been an increasing use of transparent plastics in the optical field. It is desirable to use refractive index in analytical determinations with respect to plastics and the refractive index is also useful in determining their purity.

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[1] These methods were accepted as tentative by the Society and appear in the 1939 Book of A.S.T.M. Standards, Part III.

These factors have led to the development of the proposed Tentative Method of Text for Index of Refraction of Transparent Organic Plastics.

Plastics have now found their way into all sorts of fields which bring them into physical contact with various substances, such as water, cosmetics and various liquids, which are likely to attack them chemically and change their various physical characteristics and appearance. The increasing demand for greater resistance to these elements led to the development of the proposed Tentative Method of Test for Resistance of Plastics to Chemical Reagents.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
NEW TENTATIVE STANDARDS			
Test for Index of Refraction of Transparent Organic Plastics	14	0	2
Test for Resistance of Plastics to Chemical Reagents	15	0	1

These tentative methods have been submitted to letter ballot of the committee which consists of 56 voting members; 16 members returned their ballots, with the results shown in Table I.

This report has been submitted to letter ballot of the committee which consists of 56 voting members; 29 members returned their ballots, of whom 27 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. E. EMLEY,
Chairman.

W. A. EVANS,
Secretary.

REPORT OF COMMITTEE E-1

ON

METHODS OF TESTING

Committee E-1 on Methods of Testing held a meeting in Atlantic City, N. J., on June 30, 1938. A meeting of the Advisory Committee was held in Philadelphia, Pa., on June 1, 1939.

The Executive Committee of the Society appointed three representatives-at-large to serve on the Advisory Committee, namely, W. H. Fulweiler, Consulting Chemist, P. G. McVetty, Westinghouse Electric and Manufacturing Co., and H. F. Moore, University of Illinois, each for a three-year term, expiring in 1941.

Subsequent to the 1938 annual meeting, Committee E-1 presented to the Society through Committee E-10 on Standards the following recommendations:

Tentative Specifications for Sieves for Testing Purposes (Wire Cloth Sieves, Round-Hole and Square-Hole Screens or Sieves) (E 11 - 38 T), to replace immediately the Standard Specifications for Sieves for Testing Purposes (E 11 - 26), and for Round-Hole Screens for Testing Purposes (E 17 - 36), and

Revision of Tentative Method of Bend Testing for Ductility of Metals (E 16 - 31 T).

These recommendations were accepted[1] by Committee E-10 on August 25, 1938, and appear in the 1938 *Proceedings*.[2]

During the year the Advisory Committee considered requests from Technical Committee XII on Laboratory Glassware for an extension of its scope to include chemical porcelain used in laboratory apparatus, and to undertake work on metalware apparatus. It was believed that study by the technical committee of requirements for ceramic laboratory apparatus prescribed in A.S.T.M. standards would serve to bring about greater uniformity in the parts specified and accordingly this request was approved. A special committee under the chairmanship of H. M. Hancock, after reviewing the requirements for metalware apparatus appearing in Society standards, reported that the standardization of such apparatus as specified in A.S.T.M. standards should be a constituted function of the Society. The special committee pointed out that while "laboratory metalware apparatus" was rather difficult to define accurately it appeared desirable to limit consideration to portable or mobile apparatus which is normally catalogued and stocked by laboratory supply houses. It was further suggested that the program at first should be limited to receiving, considering, and approving newly proposed metalware apparatus or the revision of metalware apparatus at present specified in A.S.T.M. standards. This request was also approved and the title of Technical Committee XII was changed to "Laboratory Apparatus" in order to cover the enlarged scope.

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[1] In submitting these recommendations to Committee E-10 on Standards, Committee E-1 reported the following results of the letter ballot vote of a total of 41 ballots returned from a committee membership of 45: E 11 - 38 T, affirmative 34, negative 0, ballots marked "not voting" 7; E 16 - 38 T, affirmative 27, negative 0, ballots marked "not voting" 14.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 1289, 1298 (1938); also 1938 Book of A.S.T.M. Tentative Standards, pp. 1607, 1630.

Accelerated Weathering Tests.—There has come to the attention of Committee E-1 the interest of Society committees in accelerated weathering tests, having in mind specifically the use of apparatus employing ultra-violet light and moisture. This type of test has been applied to roofing asphalts, paints, rubber, textile materials, and more recently to plastics, so that several of the standing committees of the Society would be concerned. A conference on this subject is to be held during this annual meeting, to which representatives of the interested standing committees are invited, in order to provide an opportunity for an exchange of views and for a general discussion of the problems involved, with the thought that Committee E-1 may be of assistance in correlating the present considerations and in furthering future work on this subject.

Bearing Tests of Pipe.—A special committee, composed of the following representatives of the standing committees interested in bearing tests of pipe, has reviewed this subject, looking toward the preparation of a single standard covering bearing tests for the several types of pipe covered by A.S.T.M. specifications:

J. T. MacKenzie, representing Committee A-3 on Cast Iron,
W. J. Schlick, representing Committee A-3, and Committee C-6 on Drain Tile,
R. G. Scott, representing Committee C-4 on Clay Pipe,
E. F. Kelley, representing Committee C-13 on Concrete Pipe, and
H. F. Clemmer, representing Section on Flexure Testing, Committee E-1.

A draft of proposed Methods of Test for Crushing Strength of Pipe (Two-Edge, Three-Edge, and Sand-Bearing Methods) has been prepared and is now receiving consideration in the special committee.

I. REVISION OF TENTATIVE STANDARD

The committee recommends that the Tentative Method of Test for Softening Point by Tapered Ring Apparatus (E 28 – 36 T) be revised and continued as tentative, as proposed by Technical Committee II (E. C. Bingham, chairman).

II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative standards be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Specifications for Sieves for Testing Purposes (Wire Cloth Sieves, Round-Hole and Square-Hole Screens or Sieves) (E 11 – 38 T),[3] revised as proposed by Technical Committee III (L. T. Work, chairman), and

Tentative Method of Bend Testing for Ductility of Metals (E 16 – 38 T),[4] revised as proposed by Technical Committee I (H. F. Moore, chairman).

III. SPECIFICATIONS FOR THERMOMETERS

The committee recommends that the thermometer requirements appearing at present in the Society's tentative and standard methods of test be consolidated into two general specifications entitled "Standard Specifications for A.S.T.M. Thermometers (E 1 – 39)"[3] and "Tentative Specifications for A.S.T.M. Thermometers (E 1 – 39 T),"[3] as proposed by Technical Committee XII (W. H. Fulweiler, chairman). The tentative specifications cover those thermometers formerly appearing in A.S.T.M. tentative methods. It is intended that the tentative specifications, when formally adopted, will be incorporated in the standard.

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[3] These specifications were accepted by the Society and appear in the 1939 Book of A.S.T.M. Standards, Parts II and III.

[4] This revised method was adopted as standard by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part I.

In order to determine whether they are in accord with current practice, the following specifications have been reviewed and have been found to be satisfactory in their present form:

Standard Specifications for:

A.S.T.M. Partial-Immersion Thermometer for General Use, −20 to +150 C., 0 to +300 F. (D 182 – 25),

A.S.T.M. Partial-Immersion Thermometer for General Use, −5 to +300 C., +20 to +580 F. (D 183 – 25), and

A.S.T.M. Partial-Immersion Thermometer for General Use, −5 to +400 C., +20 to +760 F. (D 184 – 25).

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF TENTATIVE STANDARD			
Test for Softening Point by Tapered Ring Apparatus (E 28 – 36 T)	14	0	12
II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for Sieves for Testing Purposes (Wire Cloth Sieves, Round-Hole and Square-Hole Screens or Sieves) (E 11 – 38 T), as revised	19	0	7
Bend Testing for Ductility of Metals (E 16 – 38 T), as revised	19	0	7
III. SPECIFICATIONS FOR THERMOMETERS			
Std. Spec. for A.S.T.M. Thermometers	17	0	9
Tent. Spec. for A.S.T.M. Thermometers	17	0	9

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 53 members; 26 members returned their ballots, with the results shown in Table I.

ACTIVITIES OF TECHNICAL COMMITTEES

Technical Committee I on Mechanical Testing (H. F. Moore, chairman):

Brief summaries of the work of the various sections of this technical committee are presented below.

Section on Tension Testing (R. L. Templin, chairman).—This section held a meeting in Columbus, Ohio, on March 8, 1939, at which a number of matters were discussed.

The representative on the section of Committee A-1 on Steel submitted a draft of proposed methods for tension tests of tubular products involving a modification of the Standard Methods of Tension Testing of Metallic Materials (E 8 – 36). This is to be considered carefully by the section during the coming year.

The Proposed Recommended Practices for Designation of Numerical Requirements in Standards were discussed, and it was the general opinion that the proposed methods are too complicated for use in connection with ordinary tension test data.

After considerable discussion of subsize tension specimens, with especial attention to subsize specimens mentioned in the Federal specifications, it was decided that the present provisions in Methods E 8 for subsize specimens geometrically similar to the standard ½-in. specimen were adequate. It was, however, voted that the section recommend that illustrations of subsize specimens included in the Federal specifications be added to Methods E 8. In this connection, British and German standard test specimens were discussed, and certain modifications recommended by vote of the section in the dimensions of the standard ½-in. tension test specimen.

Proposed methods of gripping wire specimens were also discussed. Conflicting reports of the effectiveness of the methods will make further study necessary. The progress of the investigation under way by the Section on Effect of Speed of Testing was discussed. After hearing reports from Watertown

Arsenal on various tests on small specimens, it was the opinion of the section that this material was quite suitable for publication by the Society.

Section on Compression Testing (M. F. Sayre, chairman).—This year the section has been giving attention to a revision of the Tentative Methods of Compression Testing of Metallic Materials (E 9 - 33 T) and to the preparation of methods of compression testing of non-metallic materials. There has just come to its attention a report on the pack method of compression testing of thin specimens, which is to be considered for inclusion in Methods E 9.

Section on Bend Tests for Ductility (A. B. Kinzel, chairman).—Subsequent to the last annual meeting a revision of the Tentative Method of Bend Testing for Ductility of Metals (E 16 - 31 T) was accepted by the Society through Committee E-10 on Standards, as mentioned earlier in this report.

During the year, at the request of Subcommittee XIII on Methods of Physical Tests of Committee A-1 on Steel, the committee has given consideration to a modification of the section on scope of the revised Method E 16 - 38 T.[2] The proposed revision, which is indicated below, is acceptable to Subcommittee XIII and has received approval by letter ballot of this section as well as of Technical Committee I. In view of the length of time that Method E 16 has had a tentative status, it is recommended that it be approved for reference to letter ballot of the Society for adoption as standard, with the following revision:

Section 1.—Change to read as follows by the addition of the italicized words:

> 1. This method of bend testing consists essentially of bending the specimen by means of forces at the ends and without introducing additional forces at the point of maximum bending. This is followed by measurements of the elongation of the outside fibers at the point of maximum bending. This is known as free bending with measurement of the fiber elongation. *The method was developed primarily for the testing of welds. It is not intended to be substituted for the more simple and wholly adequate bend test requirements now commonly specified in the Society specifications for various wrought steel products.*

Note.—Change the first sentence of the Note following Section 1 from its present form: namely,

> Although most of the work with this test has been carried out on rolled iron and steel, sufficient work has been done with other forms of ferrous material, as well as with hardened copper alloys and other non-ferrous metals, to show that the principles involved are applicable, although it will be necessary to work out the details in each case.

to read as follows:

> Although rolled steel plate was used to study the various factors involved, sufficient work has been done with welds, hardened copper alloys and other non-ferrous metals to show that the principles are applicable, although it will be necessary to work out the details in each case.

Section on Indentation Hardness (J. R. Townsend, chairman).—This section held a meeting in Atlantic City, N. J., on July 1, 1938. Plans for revising the Standard Methods of Rockwell Hardness Testing (E 18 - 36) were discussed, including changes in dimensions of penetrators and a study of methods of testing using the superficial hardness scales.[5] Plans were also discussed for the preparation of conversion tables between Brinell, Rockwell, Vickers, and other hardness scales. Progress was reported in the preparation of permanent (non-aging) standard blocks for B 40 Rockwell scale.

Two papers on the subject of hardness to be presented at this annual meeting of the Society have been sponsored by this section: one by R. L. Peek, Jr., and W. E. Ingerson on "Analysis of Rockwell Hardness Data," and the other by W. E. Ingerson on "Rockwell Hardness of Cylindrical Specimens."[6]

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[5] See Editorial Note, p. 526.

Section on Testing Thin Sheet Metals (C. H. Marshall, chairman).—This section held a meeting in Atlantic City, N. J., on June 30, 1938. At this meeting the general plans of the section for future work were considered, and the discussion indicated that problems of thin sheet metal testing were being met in the work of many of the other sections. It was decided to approach the Section on Flexure Testing concerning the flexure testing of thin sheet metals. In view of studies reported by the Section on Bend Tests for Ductility, it was decided to be inexpedient for the Thin Metals Section to study this test further at this time. The cupping test does not seem to have been developed to the point where a serviceable standard can be written.

Section on Impact Testing (W. W. Werring, chairman).—A meeting of this section was held on June 29, 1938, in Atlantic City, N. J. This meeting followed the Symposium on Impact Testing,[7] sponsored by this section at the last annual meeting, and it was the opinion of the section that the discussion elicited by the symposium justified the previous decision of the committee to rewrite the Tentative Methods of Impact Testing of Metallic Materials (E 23 - 34 T) so that they will be more informative and less rigid in detail. An outline of the proposed study includes (*1*) the expansion of the section on scope to include an outline of the effect of velocity, temperature, and shape and size of notch; (*2*) a general description of the apparatus used so as to cover types other than the pendulum type machine; (*3*) the inclusion in the methods of the key-hole notch specimen which is preferred for some metals; and (*4*) an amplification of the appendix to include an explanation of impact-tension tests. This program is now under way and will be given further consideration at a meeting of the section to be held during this annual meeting.

Section on Effect of Speed of Testing (P. G. McVetty, chairman).—This section held a meeting on March 7, 1939, in Columbus, Ohio, with a large attendance. During the year there has been prepared by F. G. Tatnall an extensive Bibliography on the Effect of Speed of Testing. Arrangements have been made to keep this bibliography up to date for the files of the committee.

At the March meeting there was discussed the investigation now under way on the effect of speed of testing on the properties of metals. This investigation is being conducted at the University of Illinois under the immediate charge of P. G. Jones and under the direct observation of H. F. Moore. The apparatus used is a modification of the apparatus used by P. G. Jones and F. E. Richart in their study of the effect of speed of testing on concrete.[8] This apparatus is designed to avoid speed effects so far as possible in the apparatus itself. In the current tests of metals, two methods of determining rate and magnitude of loading are used and apparently they check each other very well at various speeds of testing. Tests have been run on S.A.E. 1020 steel, S.A.E. 1050 steel, a low-alloy steel, brass, copper, and two aluminum alloys. In a general way the results indicate that, within the range of speeds of testing which can be used with ordinary testing machines, there is a distinct effect of rate of strain upon yield strength and tensile strength, and a somewhat slighter effect upon elongation and reduction of area. However, these effects are not great, and rather wide tolerances of rate of strain or rate of loading could be permitted without introducing any serious error.

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[6] See pp. 1270 and 1281.

[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, pp. 21 to 156 (1938).

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part II, p. 380 (1936).

In the discussion of the progress of this investigation, differences of opinion were developed as to the adequacy of "free-running" speed of head of testing machine as a criterion for speed of testing. This speed of head seemed to be more suitable as a criterion of speed for testing of ductile materials beyond yield strength, including the determination of tensile strength, elongation, and reduction of area than it was for determination of yield strength. A request is being made of the A.S.T.M. Research Fund for a contribution of $300 in order to continue this work during the next year, when it is hoped to have completed a rather large number of tests of metals. The object of this investigation is a research on the effect of rate of strain on the properties of materials, covering rates of strain which can be used in ordinary tension tests, and the methods used in the present investigation are not proposed, nor are they suitable, for routine testing. It is hoped to establish workable criteria and tolerances for rates of testing of metals. In this investigation contributions of material or money, or both have been received from the following:

Dow Chemical Co.,
National Smelting Co.,
Aluminum Company of America,
Baldwin-Southwark Corp.,
American Brass Co.,
Westinghouse Electric and Manufacturing Co.,
General Cable Corp.,
Bridgeport Brass Co.,
Chase Brass and Copper Co.,
International Nickel Co.,
Jones & Laughlin Steel Corp., and
University of Illinois.

The possibility of investigating the effect of still higher rates of speed of testing than those covered by the present investigation was discussed, and consideration given to laboratories where such an investigation might be carried out.

Section on Elastic Strength of Materials (F. B. Seely, chairman).—During the year, inquiries have been received concerning the correlation of total elongation under load at yield strength and equivalent "offset" from the straight-line portion of the stress-strain diagram. The following relation has been calculated and sent to all inquirers and to all members of the section. It is here presented as information:

$$q = e_t - 100 \frac{Y}{E}$$

where:

Y = specified yield strength, in pounds per square inch,
e_t = percentage elongation under load at yield strength,
q = equivalent "offset" for determining yield strength by the "offset" method, in per cent, and
E = modulus of elasticity of the material, in pounds per square inch.

During the year this section has been observing with interest the growing use of "yield strength" as a criterion for practical elastic strength of materials. There has been a considerable amount of correspondence with laboratories and with other standing committees of the Society.

The Sections on Flexure Testing and on Calibration of Testing Machines and Apparatus have no definite matters to report this year. Both sections have problems of standardization before them and hope to report more definite action during the coming year.

Technical Committee II on Consistency, Plasticity, and Related Properties (E. C. Bingham, chairman):

Additional comments on the Tentative Definitions of Terms Relating to Rheological Properties of Matter (E 24 - 37 T) were received during the year from interested standing committees of the Society. It is expected that further consideration will be given to the definitions in order to bring them in line with the definitions published by the Society of Rheology.

On the recommendation of the special committee under the chairmanship of T. H. Rogers, revisions of the Tentative Method of Test for Softening Point by Tapered Ring Apparatus (E 28 - 36 T)[9] have been submitted to letter ballot of Technical Committee II which consists of 26 members; 23 members returned their ballots, of whom 16 have voted affirmatively, 0 negatively, and 7 members marked their ballots "not voting." It is accordingly recommended that the tentative method be revised as indicated below and continued as tentative:

Title.—Change to read as follows by the addition of the italicized words and the omission of the word in brackets:

> Tentative Method of Test for Softening Point [by] (*Ball and* Tapered Ring Apparatus).

Section 3.—Change the second and third sentences to read as follows by the addition of the italicized words and the omission of the words and figures in brackets:

> A quantity at least twice that necessary to fill the desired number of rings and in no case less than 40 g. shall be melted immediately in a clean container, using an oven, *hot plate*, sand or oil bath to prevent local overheating. Care shall be taken to avoid incorporating air bubbles in the sample, [which should not be heated more than 30 C. (54 F.) above its softening point, in the case of materials having a softening point below 121 C. (250 F.), except rosin, or more than 50 C. (90 F.) for rosin and materials with softening points above 121 C. (250 F.), for materials having a long softening range it may be necessary to increase this to 85 C. (185 F.)] *which shall not be heated above the temperature necessary to pour the material readily without inclusion of air bubbles.* The time from the beginning of heating to the pouring of the sample *shall* not [to] exceed 15 min.

Fig. 2.—It is proposed to revise the design of the ball-centering guide to show the use of round openings in the side of the guide rather than square openings, in order to facilitate its manufacture.

Section 4 (a).—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

> 4. (*a*) Assembling Apparatus.—The glass container shall be filled to a depth not less than 9 cm. (3.5 in.) with freshly boiled distilled water (or with glycerin for materials melting above 80 C. (176 F.)) which has been cooled to not less than 45 C. (81 F.) below the anticipated softening point but in no case lower than 5 C. (41 F.) for materials melting below 80 C. (176 F.) and in no case lower than 35 C. (95 F.) for materials melting above 80 C. (176 F.). *Provision shall be made for centering the ball on the upper surface of the sample, either by use of the ball guide or by making a slight indentation in the center of the sample. The latter may be done by pressing the ball or a rounded rod into the material at this point. In the case of hard materials the rod may be heated.* The ring containing the sample and ball guide, *if used*, shall be suspended in the water so that the lower surface of the filled ring is 2.5 cm. (1 in.) above the bottom of the glass container (Fig. 1) or 2.5 cm. above the upper surface of the lower horizontal plate which is at least 1.3 cm. ($\frac{1}{2}$ in.) above the bottom of the glass vessel (Fig. 3) and so that its upper surface is at least 5.1 cm. (2 in.) below the surface of the water. The ball shall be placed in the water but not on the specimen. The thermometer shall be suspended so that the bottom of the bulb is level with the bottom of the ring and within 1.0 cm. ($\frac{3}{8}$ in.) but not touching the ring. The initial temperature shall be maintained for 15 min. With suitable forceps the ball shall be

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[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 1186 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 1621.

placed in the center of the upper surface of the material in the ring [using the ball guide to hold the ball in this position].

Committee D-4 on Road and Paving Materials, which is responsible for the Standard Method of Test for Softening Point of Bituminous Materials (D 36 – 26), is undertaking, in its Subcommittee on Softening Point, a cooperative investigation of the use of an air bath instead of a liquid bath in the ring-and-ball softening point test. Technical Committee II has been invited to cooperate and several of its members have indicated their willingness to participate in this investigative study.

Technical Committee III on Particle Size and Shape (L. T. Work, chairman): Technical Committee III reports on two matters relating to standards, technical papers for presentation at the annual meeting of the Society, and the problem of reorganization of the committee.

Under the joint sponsorship of the National Bureau of Standards and the Society, Sectional Committee Z23, functioning under the procedure of the American Standards Association, has developed specifications for sieves for testing purposes. In these specifications have been combined the detailed requirements for coarse and fine sieves, both woven wire cloth and perforated plate. The specifications were submitted by Technical Committee III to the Society through Committee E-10 on Standards subsequent to the last annual meeting, and the Specifications for Sieves for Testing Purposes (E 11 – 38 T)[10] were accepted for publication as an A.S.T.M. tentative standard as mentioned earlier in this report. During the past year a number of minor points have been brought to the attention of the committee and have been incorporated in a revision of the specifications which was submitted to letter ballot in the Sections on Fine Sieves and on Coarse Screens together with the recommendation that the specifications be adopted as standard. Out of a membership of 23, 19 ballots have been returned, all of which were affirmative. Technical Committee III accordingly recommends that Specifications E 11 – 38 T, as revised, be approved for reference to letter ballot of the Society for adoption as standard.[11]

The Tentative Method of Analysis for the Particle Size Distribution of Subsieve Size Particulate Substances (E 20 – 33 T) was subject to some consideration during the past year by the Section on Subsieve Sizes (D. L. Gamble, chairman). The method is basically applicable in the pigment field and it is probable that this method will be revised specifically for that purpose. The methods will, therefore, be continued as tentative for another year.

Technical Committee III has served in an advisory capacity with respect to the presentation at the 1939 annual meeting of the Society of two papers on particle size measurement, in which representatives of manufacturers describe their equipment and its performance.[12]

After a number of years of service D. L. Gamble, who has guided the work of the Subsieve Section, finds that it is impossible to continue in charge of that work. His very effective service is greatly appreciated and his loss is lessened by the fact that he will remain as a special adviser member.

The changing nature of the emphasis on particle size distribution has necessitated a reorganization of the sections of Technical Committee III. The work of the Sections on Fine Sieves and on Coarse Screens has been merged through the development of a single standard, and it is, therefore, planned to combine these two groups into one section.

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[10] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1289 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1607.

[11] The revised specifications were adopted as standard by the Society and appear in the 1939 Book of A.S.T.M. Standards, Parts II and III.

[12] M. N. States, "Specific Surface and Particle Size Distribution of Finely Divided Materials," see p. 795, and Pierce M. Travis, "Measurement of Average Particle Size by Sedimentation and Other Physical Means," published in ASTM BULLETIN, No. 102, January, 1940, p. 29.

The diversity of problems in the subsieve range is so great as to warrant the formation of two sections, one on Ground Products and Soils, and one on Pigment Type Materials. C. E. Barnett of the Research Division of the New Jersey Zinc Co., has been appointed chairman of the Section on Pigment Type Materials, and the chairman of Technical Committee III will temporarily serve as chairman of the Section on Ground Products and Soils. Reorganization plans will be perfected during the coming year.

Technical Committee VII on Chemical Composition (G. E. F. Lundell, chairman):

At the request of Committee C-4 on Clay Pipe, a special group under Technical Committee VII is giving consideration to the test for resistance to action of acids on clay pipe which is of interest in connection with the Standard Specifications for Clay Sewer Pipe (C 13 – 35). A suggested revision of the test, comprising a change in form rather than substance, for the purpose of clarifying the description of the method and omitting misleading wording, is now being prepared for submission to the technical committee at its next meeting.

Technical Committee IX on Interpretation and Presentation of Data (H. F. Dodge, chairman):

During the past year this technical committee has served in an advisory capacity on a number of problems relating to the use of statistical methods in the analysis and presentation of data.

It has cooperated closely with Committee D-13 on Textile Materials in the preparation of a proposed procedure for determining the number of tests that should be made on any quality characteristic in order to regulate to a desired degree the sampling errors of averages obtained from samples. Inquiries received during the year on several subjects suggest the advisability of preparing a revision of the A.S.T.M. Manual on Presentation of Data. The committee is considering the possibilities of undertaking such a revision in 1940 to cover control charts for the coefficient of variation, and to include a new supplement dealing with the relationship between the number of tests and the sampling errors of averages.

Technical Committee X on Conditioning (Robert Burns, chairman):

This technical committee was organized at a meeting held in Atlantic City, N. J., on June 30, 1938, with the following scope:

> *Scope.*—Promote standardization by encouraging the adoption of existing methods of conditioning and by minimizing so far as possible the number of required new methods; provide a clearing house of information obtained by standing committees, and furnish educational and advisory service to the Society.

After a definition of conditioning has been decided upon the next specific effort will be to procure a review of the definitions included in the Standard Method of Determining Relative Humidity (D 337 – 34) with the idea of obtaining general acceptance of these definitions when considered by a broader range of interests than that of Committee D-13 on Textile Materials, which committee is responsible for Method D 337. The technical committee will also consider the definition of average room conditions officially adopted by Committee D-9 on Electrical Insulating Materials, namely, 40 per cent relative humidity at 25 C. Data will be presented giving the basis for this definition.

The technical committee gives advisory service to standing committees of the Society and keeps them acquainted with the related activities of other committees. This has been instrumental in bringing about more uniformity in the committees' approach to conditioning problems and has helped to minimize duplication of effort. Several new conditioning procedures now under active consideration by Committee D-9 and by Committee D-20 on Plastics are being prepared with the assistance of the members of this technical committee.

Technical Committee XI on Designation and Interpretation of Numerical Requirements (J. A. Gann, chairman):

Technical Committee XI held a meeting in Columbus, Ohio, on March 6, 1939, and plans to hold a further meeting in Atlantic City, N. J., during this annual meeting. The technical committee has considered during the year the suggestions received from A.S.T.M. standing committees concerning the Proposed Recommended Practices for Designation of Numerical Requirements in Standards, published as information since 1936.[13] The committee has also solicited comments from other interested groups, including a number of Government agencies.

The replies and suggestions received have formed the basis of certain changes in the recommended practices now under consideration. Particular attention is being given to the method of rounding off numbers that are exactly halfway between two rounded off values. It is expected that decision on the desirable changes will be reached at the June meeting of the technical committee so that action may be taken to submit the recommended practices to the Society for publication as tentative.

Technical Committee XII on Laboratory Apparatus (W. H. Fulweiler, chairman):

This technical committee held two meetings during the year: in Atlantic City, N. J., on June 30, 1938, and in Vineland, N. J., on May 18, 1939. As mentioned earlier in this report, at the request of the technical committee its scope has been extended to include metalware apparatus and ceramic laboratory apparatus. In view of this enlargement in scope, the title of the committee has been changed; suitable additions will be made to the personnel of the committee, and new sections on each of these subjects will be organized.

The committee's attention has been directed to the fact that the number of different kinds of centrifuge tubes in use is rapidly increasing; steps will accordingly be taken, in cooperation with Committee D-2 on Petroleum Products and Lubricants, to discuss with other interested societies the desirability of appointing a cooperative survey committee in an effort to standardize these tubes further and to minimize the number of types of tubes in use.

At the request of Technical Committee XII the National Bureau of Standards has agreed to undertake, when thermometers are submitted to the Bureau to determine conformity or otherwise with A.S.T.M. standards, to issue a certificate which will state whether or not the thermometer complies with the applicable A.S.T.M. standard.

Section A on Thermometers (R. M. Wilhelm, chairman).—At the request of Committee E-10 on Standards, consideration has been given to the manner in which the specifications for thermometers are now published in A.S.T.M. standards. At the present time the thermometer requirements, in general, appear in each of the methods with which the thermometers are used, as a result of which there is considerable duplication in the case of certain types of thermometers, especially those used for the distillation test. With the consent of the interested standing committees, consideration has been given during the year to publishing specifications for thermometers separately and including in the methods a reference to the particular thermometer that is applicable. A special committee, under the chairmanship of Valentine Hiergesell, has prepared general specifications for A.S.T.M. thermometers, comprising a consolidation of the thermometer requirements appearing at present in A.S.T.M. standards, which are being presented for publication this year as mentioned earlier in this report.

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[13] *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 527 (1936).

Section B on Hydrometers (J. P. Bader, chairman).—This section has prepared detailed specifications for hydrometers used in testing creosote oil for use in connection with the Standard Method of Test for Specific Gravity of Creosote (D 368 - 33). The section plans to consider detailed requirements for the hydrometer used in the mechanical analysis of soils (A.S.T.M. Method D 422 - 38 T). The paper on "Testing of Hydrometers" by E. N. Hurlburt which was contemplated for inclusion in this report will not be available until 1941.

Section C on Volumetric Glassware (J. J. Moran, chairman).—This section has reviewed and recommended improvements in requirements for calibrated glass apparatus appearing in several new and revised methods being presented to the Society this year for publication. The section has also reviewed the draft British Standard Specification for Apparatus for the Determination of Water by Distillation with an Immiscible Liquid, and comments have been forwarded to the British Standards Institution. The apparatus specified in the British draft is in some respects superior to present A.S.T.M. designs and the section is considering a general specification for this type of apparatus for submission to Technical Committee XII.

Section D on Laboratory Glassware (F. F. Shetterly, chairman).—This section has reviewed and proposed improvements in requirements for certain pieces of laboratory glassware appearing in several existing A.S.T.M. methods. These recommendations have been presented for adoption to the standing committees responsible for the methods in question.

This report has been submitted to letter ballot of the committee which consists of 53 members; 26 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. H. FULWEILER,
Chairman.

P. J. SMITH,
Ex-officio Secretary.

EDITORIAL NOTE

Subsequent to the annual meeting Committee E-1 presented to the Society through Committee E-10 on Standards a proposed tentative revision of the Standard Methods of Test for Rockwell Hardness of Metallic Materials (E 18 - 36). This tentative revision, in the form of a new Tentative Method of Test for Rockwell Superficial Hardness of Metallic Materials (E 18 - 39 T), was accepted by Committee E-10 on October 23, 1939, and appears in the 1939 Book of A.S.T.M. Standards, Part I.

REPORT OF COMMITTEE E-2

ON

SPECTROGRAPHIC ANALYSIS

While during the past year most of the work of Committee E-2 on Spectrographic Analysis has been carried on by correspondence, meetings of the main committee and of Subcommittees I and III were held during the spring meetings of A.S.T.M. Committees in Columbus, Ohio, on March 8, 1939, at Ohio State University.

Ten new members were elected to the committee during the year and two members resigned, leaving a total membership of 52.

Committee E-2, as one phase of its activity, sponsored the publication of the "Index to the Literature on Spectrochemical Analysis 1920 - 1937," prepared by W. F. Meggers and B. F. Scribner. This bibliography was issued as a separate publication by the Society in January, 1939.

Subcommittee I on Apparatus and Equipment (W. R. Brode, chairman) held one meeting during the year, at the spring group meetings at which several types of spectrographs, including two commercial grating instruments, were exhibited.

Subcommittee II on Fundamental Methods and Technique (O. S. Duffendack, chairman) is sponsoring a Round-Table Discussion on Quantitative Spectrography to be held at this annual meeting of the Society. The discussion will consider the recognition of various fundamental methods of excitation, photometry, and other phases of spectrochemical analysis with the purpose in view of establishing master methods, both for qualitative and quantitative analysis.

Subcommittee III on Quantitative Methods and Applications (M. L. Fuller, chairman) has been especially active; it has organized the following six groups, each assigned to a class of materials for which there appears to be a demand for methods of spectrographic analysis:

1. Copper, Nickel, and Their Alloys (C. H. Davis, chairman),
2. Lead, Tin, Antimony, Bismuth, and Their Alloys (A. E. Ruehle, chairman),
3. Aluminum, Magnesium, and Their Alloys (H. V. Churchill, chairman),
4. Zinc, Cadmium, and Their Alloys (M. L. Fuller, chairman),
5. Ferrous Metals (W. R. Koch, chairman), and
6. Non-Metals (in course of organization).

Subcommittee III has considered several proposed changes in the Tentative Methods for the Analysis of Pig Lead (E 25 - 37 T), Zinc (E 26 - 35 T), and Zinc Alloy Die Castings (E 27 - 37 T). It has decided not to recommend any modifications in the methods until the suggestions have been more widely circulated among the members of Committee E-2 and others who may be interested.

The work of Subcommittee III has led to a recommendation to the main committee, that the usefulness and availability of methods of analysis for specific materials will best be promoted by the establishment and publication of master methods. Such master methods would include procedures for the use of internal standards, comparison standards, self-electrodes, and supporting electrodes. Committee E-2 has ratified this recommendation and assigned the project to Subcommittee II.

Subcommittee IV on Accessory Uses of the Spectrograph (C. C. Nitchie, chairman) has as yet done little along these lines, principally because of a lack of demand from other committees of the Society. It is expected that from their activities needs may arise which can be satisfied by some application of the spectrograph.

Subcommittee V on Standards and Pure Materials (T. A. Wright, chairman) keeps in touch with new developments in its field and serves as a very useful clearing house for information as to sources and availability of standards and pure metals. Many requests for information were handled during the year.

This report has been submitted to letter ballot of the committee which consists of 52 members; 38 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. V. CHURCHILL,
Chairman.

B. F. SCRIBNER,
Secretary.

REPORT OF COMMITTEE E-3

ON

CHEMICAL ANALYSIS OF METALS

Committee E-3 on Chemical Analysis of Metals held one meeting during the year: on June 29, 1938, in Atlantic City, N. J., during the annual meeting of the Society. The committee plans to hold a further meeting during this annual meeting.

During the year Committee E-3 presented to the Society through Committee E-10 on Standards revisions of the Tentative Methods of Chemical Analysis of Ferro-Alloys (A 104 – 36 T), and Sampling Ferro-Alloys (A 103 – 36 T). The revision of Tentative Methods A 104 (redesignated E 31 – 38 T) was accepted by Committee E-10 on August 25, 1938, and the revision of Tentative Methods A 103 (redesignated E 32 – 39 T) was accepted[1] on March 4, 1939. The revised methods appear in Supplements to A.S.T.M. Methods of Chemical Analysis of Metals, issued as separate reprints.

The committee is at present working on revisions of the following tentative methods:

Tentative Methods of:

Sampling Molybdenum Salts and Compounds for Metallurgical Use (A 156 – 34 T),
Chemical Analysis of Pig Lead (B 35 – 36 T),
Chemical Analysis of Aluminum and Light Aluminum Alloys (B 40 – 36 T),
Chemical Analysis of Slab Zinc (Spelter B 36 – 36 T), and
Chemical Analysis of Metallic Materials for Electrical Heating (B 71 – 34 T).

The various divisions of the committee have been active during the year. Division A on Ferrous Metals (G. E. F. Lundell, chairman) is working on methods for the determination of aluminum, columbium, lead, and selenium in steels. A new subcommittee under the chairmanship of T. R. Cunningham has started work on a revision of Tentative Methods B 71 – 34 T. Arba Thomas was elected chairman of the division for the ensuing term of two years.

Division B on Non-Ferrous Metals (R. P. Nevers, chairman) is continuing work on the revision of the methods for copper-base alloys, pig lead, aluminum, and spelter.

Division C on Sampling (T. A. Wright, chairman), through its various subcommittees, is engaged in the preparation of methods for the sampling of various metals and alloys.

Division D on General Analytical Methods (B. L. Clarke, chairman) has cooperated with Division B on methods for the analysis of copper-base alloys and slab zinc and is reviewing available methods for the analysis of commercial tin.

ADOPTION OF TENTATIVE STANDARD AS STANDARD

The committee recommends that the Tentative Methods of Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron (E 30 – 36 T)[2] be approved for reference to letter ballot of the Society for adoption as standard.[3] This recommendation has been referred to letter ballot of the committee which consists of 56 members; 47 members returned their ballots, of whom 39 have voted affirmatively, 0 negatively, and 8 members marked their ballots "not voting."

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[1] In submitting these recommendations to Committee E-10 on Standards, Committee E-3 reported results of the letter ballot vote as follows: E 31 – 38 T, of a total membership of 59, 52 members returned their ballots, of whom 41 voted affirmatively, 0 negatively, and 11 members marked their ballots "not voting"; E 32 – 39 T, of a total membership of 57, 43 members returned their ballots, of whom 36 voted affirmatively, 0 negatively, and 7 members marked their ballots "not voting."

This report has been submitted to letter ballot of the committee which consists of 56 members; 48 members returned their ballots, of whom 46 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. E. F. LUNDELL,
Chairman.

H. A. BRIGHT,
Secretary.

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[2] A S.T.M. Methods of Chemical Analysis of Metals, p. 1 (1936).

[3] These methods were adopted as standard by the Society and appear in the A.S.T.M. Methods of Chemical Analysis of Metals, p. 1 (1939).

REPORT OF COMMITTEE E-4
ON
METALLOGRAPHY

Committee E-4 on Metallography has held two meetings during the year: one in Atlantic City, N. J., on June 28, 1938, during the annual meeting of the Society, and the other on March 8, 1939, at Columbus, Ohio, during the spring committee meetings.

Committee E-4 reports a net gain during the year of two members, making a total committee membership of 52.

Subsequent to the last annual meeting, the committee presented to the Society, through Committee E-10 on Standards, a new Tentative Grain Size Chart for Classification of Steels (E 19 - 38 T) which is intended to replace, when adopted, the present Standard E 19 - 33. This recommendation was accepted[1] by Committee E-10 on August 25, 1938, and appears in the 1938 *Proceedings*.[2]

NEW TENTATIVE STANDARD

The committee recommends that new Tentative Method of Preparation of Metallographic Specimens (E 3 - 39 T)[3] be accepted for publication as tentative to replace immediately the present Standard E 3 - 36.[4]

This recommendation has been submitted to letter ballot of the committee which consists of 52 members; 32 members returned their ballots, of whom 30 have voted affirmatively, 0 negatively, and 2 members "not voting."

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Selection and Preparation of Samples (E. H. Dix, Jr., chairman) has been concerned principally with the revision of the Recommended Practice for Metallographic Testing of Ferrous and Non-Ferrous Metals (E 3 - 36). W. E. Harvey, a member of the subcommittee, acted as editor of the revision, and the assistance of experts familiar with the various metals was enlisted in the interest of securing most up-to-date information.

Subcommittee II on Nomenclature and Definitions (R. S. Williams, chairman) has reviewed the Standard Definitions of Terms Relating to Metallography (E 7 - 27) in order to ascertain whether they are in need of revision; the subcommittee recommends that no changes be made at this time.

Subcommittee IV on Photography (L. V. Foster, chairman) has been working on a revision of the Standard Rules Governing the Preparation of Micrographs of Metals and Alloys, Including Recommended Practice for Photography as Applied to Metallography (E 2 - 36) which will include an amplification of the technique of illumination as well as further information on filters, photographic plates, and paper. It is expected that this revision will be completed in time for presentation to the committee at the annual meeting.[5]

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[1] In submitting this new tentative standard to Committee E-10 on Standards, Committee E-4 reported results of the letter ballot vote as follows: Of a total membership of 51, 28 members returned their ballots, of whom 27 voted affirmatively, 0 negatively, and 1 member marked his ballot "not voting."

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1296 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1628.

[3] This method was accepted as tentative by the Society and appears in the 1939 Book of A.S.T.M. Standards, Part I.

[4] 1936 Book of A.S.T.M. Standards, Part I, p. 773.

[5] See Editorial Note, p. 532.

R. P. Loveland, a member of this subcommittee, is in charge of the section on photomicrography of the 1939 Exhibit of Photography to be held during this annual meeting of the Society. In addition, Mr. Loveland has prepared a paper on "Metallography in Color," to be presented at the annual meeting.[6]

Subcommittee VI on X-ray Methods (W. L. Fink, chairman) is in the process of correlating data and initiating work on the problems of the measurement of residual stresses, and the correlation between grain size established by X-ray diffraction and that determined microscopically. This work has as yet not progressed sufficiently to warrant a report as to its status.

Subcommittee VII on Recommended Practice for Dilatometric Analysis (L. L. Wyman, chairman) now consists of four members. Questionnaires relating to dilatometric analysis are still being received and analyzed, with definite promise of several opportunities of establishing recommended practices.

In order to determine whether it is still in accord with present practice, this subcommittee has reviewed the Recommended Practice for Thermal Analysis of Steel (E 14 - 33) and recommends that it be continued in its present form.

Subcommittee VIII on Grain Size (M. A. Grossmann, chairman) prepared the Tentative Grain Size Chart for Classification of Steels (E 19 - 38 T) which was accepted for publication as tentative subsequent to the last annual meeting, as mentioned earlier in this report. This tentative standard covers the determination of austenitic grain size in steel by a variety of methods currently in use. At the same time, the Standard Chart (E 19 - 33) on the McQuaid-Ehn test is still in force. At the meeting of Committee E-4 held in Columbus, Ohio, on March 8, the relationships between the tentative standard and the standard were discussed and certain suggestions made to further reconcile these two charts with the various practices in the trade. Further discussions will be held with a view to arriving eventually at a single standard which will embody the wishes of all concerned.[5]

This report has been submitted to letter ballot of the committee, which consists of 52 members; 32 members returned their ballots, all of whom have voted affirmatively.

Respectively submitted on behalf of the committee,

L. L. WYMAN,
Chairman.

J. J. BOWMAN,
Secretary.

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[6] This paper was presented at the annual meeting but is not yet available for publication. It is expected to be published at a later date.

EDITORIAL NOTE

Subsequent to the annual meeting Committee E-4 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Standards:

Methods of Preparation of Micrographs of Metals and Alloys, Including Recommended Practice for Photography as Applied to Metallography (E 2 - 39T), to replace immediately Standard Rules E 2 - 36, and

Classification of Austenite Grain Size in Steels (E 19 - 39T), to replace immediately both the Standard and Tentative Grain Size Charts for Classification of Steels (E 19 - 33 and E 19 - 38 T).

These recommendations were accepted by Committee E-10 on August 24, 1939, and the new tentative standards appear in the 1939 Book of A.S.T.M. Standards, Part I.

REPORT OF COMMITTEE E-7
ON
RADIOGRAPHIC TESTING

Committee E-7 on Radiographic Testing reports as follows on the work of its several subcommittees during the past year:

Subcommittee I on Radiography of Cast Metal (C. W. Briggs, chairman) has prepared proposed Tentative Methods of Radiographic Testing of Metal Castings which are intended to replace the present Standard Recommended Practice E 15 – 29 since this is now obsolete. The new recommended practice, after approval by Committee E-7, will be presented to the Society during the summer through Committee E-10 on Standards for publication as tentative.[1]

Subcommittee I is also giving consideration to the standards prepared by the U. S. Navy for radiographic inspection of steel castings for steam pressure service. It is the intention of Committee E-7 that, after approval by letter ballot vote of the committee, the proposed standards will be presented to the Society for publication.

Subcommittee II on Technical Research (H. E. Seemann, chairman) sponsored four technical papers at this annual meeting, as follows:

"Correlation of Some Mechanical Tests of Aluminum Alloys with X-ray Tests,"[2] by Tom A. Triplett and W. Lavern Howland.

"The Use of Radiography in the Development of Castings for Mass Production,"[3] by Don M. McCutcheon.

"Some Aspects of Radiographic Sensitivity in Testing with X-rays,"[4] by H. H. Lester.

"Fine Focus Radiography—Gamma Rays,"[5] by Gilbert E. Doan and Milton B. Vordahl.

Messrs. Triplett and Howland show results obtained with an X-ray tube whose projected focal area is only 0.1 mm. in diameter. This is the finest focal spot that has been used for routine industrial radiography in this country. They have found interesting correlations between macrographic structure revealed in radiographic tests and tensile impact values.

Mr. McCutcheon gives an excellent picture of the practical application of radiographic tests to the manufacture of cast crankshafts.

The paper presented by Mr. Lester was based upon cooperative work in several industrial laboratories. The work was sponsored by and reported to the Joint A.P.I.-A.S.M.E. Radiographic Committee. This is an example of the coordination and cooperation that is a basic policy of Committee E-7.

Messrs. Doan and Vordahl, using very small radium capsules, have shown that good definition may be obtained with the radium source as close as 3 in. to a

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[1] See Editorial Note, p. 534.

[2] See p. 749.

[3] Published in ASTM BULLETIN, No. 103, March, 1940.

[4] Published in ASTM BULLETIN, No. 100, October, 1939, p. 33.

[5] Published in ASTM BULLETIN, No. 103, March, 1940.

$\frac{3}{4}$-in. plate. The significance of the results lies in the fact that they point the way to a practical method of testing welded pipe lines.

Subcommittee III on Radiography of Welds and Weldments (H. H. Lester, chairman) reports considerable progress. Cooperative work done by members of the subcommittee is included in one of the technical papers mentioned above. Work is almost completed on a proposed penetrameter, including a functional definition of the instrument, and a suggested practice covering its use. This device has been adopted by the Joint A.P.I.-A.S.M.E. Radiographic Committee.

Subcommittee IV on Correlated Abstracts (W. P. Davey, chairman) has completed the laborious task of preparing a correlated abstract of important papers in the radiographic field. Only the more important of the earlier papers, but all of the more recent ones, have been included. It is expected that this valuable work will be made available to those interested through publication in the ASTM BULLETIN.[6]

Subcommittee VI on Safety (E. W. Page, chairman) sponsored a very important paper entitled "Industrial X-ray Protection," by Lauriston S. Taylor of the National Bureau of Standards. Mr. Taylor is the author of the Bureau of Standards' *Handbooks 20* and *23* on X-ray Protection and Gamma-ray Protection, respectively, and is recognized as a leading authority on this subject. The present paper, written for the benefit of industrial rather than medical radiography, has been prepared in response to a recognized need and is the most authoritative pronouncement on the subject at present available. It is expected that it will be published at an early date in the ASTM BULLETIN.[7]

Respectfully submitted on behalf of the committee,

H. H. LESTER,
Chairman.

EARNSHAW COOK,
Secretary.

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[6] Published in ASTM BULLETIN, No. 102, January, 1940, p. 26.

[7] Published in ASTM BULLETIN, No. 99, August, 1939, p. 23.

EDITORIAL NOTE

Subsequent to the annual meeting Committee E-7 on Radiographic Testing presented to the Society through Committee E-10 on Standards proposed Tentative Methods of Radiographic Testing of Metal Castings (E 15 – 39 T) to replace immediately the Recommended Practice for Radiographic Testing of Metal Castings (E 15 – 29). This recommendation was accepted by Committee E-10 on August 24, 1939, and the new tentative methods appear in the 1939 Book of A.S.T.M. Standards, Part I.

REPORT OF COMMITTEE E-9
ON
RESEARCH

In the following there is presented a brief résumé of certain principal research activities during the past year which have engaged the attention of Committee E-9 on Research, with particular reference to new projects and cooperative research. A more comprehensive review of research activities throughout the Society will, as usual, appear in the October issue of the ASTM BULLETIN.

Research Committee Activities:

The *Research Committee on Fatigue of Metals* describes in its report[1] at this annual meeting of the Society the progress that has been made in its investigation of the effect of the type of testing machine on fatigue test results. Four different types of fatigue testing machines are being used in testing specimens of heat-treated alloy steel and "as rolled" low-alloy steel. Six laboratories are cooperating. It is hoped that the tests will provide data that will answer the question: "Are the shape of the *S-N* diagram and the endurance limit obtained from a set of fatigue tests a measure of a property of the metal, or are they affected by the type of machine used, and if so, how much?" Committee E-9 has contributed $500 from the Society's Research Fund in support of this project.

The *Joint Research Committee on Effect of Temperature on the Properties of Metals* of the American Society of Mechanical Engineers and this Society is presenting a quite extensive report[2] at this meeting of the Society in which the varied activities of the committee are included. Detailed reports are included covering creep and torsion tests on carbon-molybdenum steel at the University of Michigan, and on further work at the University of Michigan on rupture tests with especial reference to effect of grain size. There is also included an attempted correlation of creep tests in tension, torsion, and internal pressures. The continuation of the work at Battelle Memorial Institute on the effect of manufacturing variables on creep is expected to furnish new and confirming data in this important consideration.

The Joint Committee during the year sponsored the publication by the two sponsor societies of a Compilation of Available High-Temperature Creep Characteristics of Metals and Alloys, a bound volume of 850 pages, giving in the form of charts, tables, and graphs extensive creep data developed by the committee covering commercial ferrous and non-ferrous metals and alloys.

The Joint Committee is sponsoring at this annual meeting a Round-Table Discussion on Effect of Sub-Atmospheric Temperatures on the Properties of Metals.[3] While there is a considerable amount of information extant bearing on the behavior of metals at low temperatures, there is a need and a demand for gathering together all the available knowledge possible on the subject in the form in which it will be most useful to engineers and metallurgists.

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[1] See p. 210.

[2] See p. 211.

[3] For résumé of discussion see p. 637.

The *Joint Committee on Exposure Tests of Plating on Non-Ferrous Metals*, composed of representatives of the American Electro-Platers' Society, the National Bureau of Standards, and this Society, is presenting a progress report[4] at this annual meeting on inspection of plated specimens listed in the 1936 and 1938 reports of the Joint Committee. These include chromium and nickel coatings on copper and brass and on zinc-base die castings; also a few zinc, nickel, and chromium coatings on steel. The current report summarizes certain major conclusions that have been drawn regarding the effect of different variables on the protective value of the coatings. Discussions are also included on the effect of cleaning and on the effect of a grease film.

The committee has under consideration the drafting of specifications for electroplated coatings on non-ferrous metals, especially brass and zinc-base die castings based on these exposure tests and on experience of producers and users.

Research Progress of A.S.T.M. Committees:

Effect of Speed of Testing on Physical Properties of Metals (Committee E-1).—This investigation, sponsored by the Section on Effect of Speed of Testing of Committee E-1, is being carried on at the University of Illinois under an agreement between the university and the Society. The title of the project is largely self-explanatory. Various types of carbon and alloy steels, and brass, copper, and two aluminum alloys are being studied. The current report[5] of Committee E-1 describes the progress being made and points to the need for further studying the effect of rate of strain upon the properties of metals.

Committee E-9 has contributed $600 from the Research Fund towards this project for the year ending June 30, 1939, which has been supplemented by contributions totaling $700 from the National Smelting Co., Aluminum Company of America, and Westinghouse Electric and Manufacturing Co. Other acknowledgments of contributions of materials and service are contained in the report of Committee E-1.

Testing of Textile Finishes (Committee D-13).—This project has been set up during the year under the general auspices of Committee D-13 on Textile Materials. The object of the research is the development of physical testing methods for the evaluation of various types of textile finishes. The principal interest is in the development of a practical, effective method for evaluating the "handle" of textile fabrics, which is the textile term to indicate the way a fabric feels when handled. The present method of evaluating this characteristic of a fabric is simply to feel it and judge the feel in comparison with the feel of other fabrics with similar finishes. This requires an individual of great experience and is at best highly subjective. An effective testing method would be of great value to all who have need to evaluate the "handle" of fabrics. Other types of finishes on which research will be carried out are crease-proofed, slip-proofed, shrink-proofed and flame-proofed finishes.

The project is being supported financially by about ten companies who have contributed $3300 for the first year's work. A research associate has been appointed who will shortly begin his duties at the National Bureau of Standards where the program will be carried out. The August ASTM BULLETIN will contain a further account of this important project.

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[4] See p. 304.
[5] See p. 520.

Moisture Content of Paperboard and of Corrugated Fiberboard Containers (Committee D-6).—Committee D-6 on Paper and Paper Products, through its Subcommittee IV on Fiberboard and Fiberboard Containers, has made substantial progress on an extensive study which has for its principal objective the securing of dependable data on the moisture content of container grades of paperboards and of corrugated fiberboard containers, resulting from conditioning these products in accordance with several specified procedures. The relationship between moisture content and certain physical properties is also being studied. This project is of fundamental importance in the development of tests and specifications for fiberboard and fiberboard containers. The program has been publicized in the technical press and the committee's report on the work is expected to be available during the coming year.

New Activities.—In addition to the projects just described, research activities on the following subjects have been started during the year by the committees named. Brief statements of each of these projects appeared in the ASTM BULLETIN for October, 1938:

- Chilled and White Iron Castings (Committee A-3)
- Glazed Building Units (Committee C-15)
- Consistency of Paint (Committee D-1)
- Painting of Structural Iron and Steel (Committee D-1)
- Acid Heat of Gasoline (Committee D-2)
- Cubic Foot Weight of Crushed Bituminous Coal (Committee D-5)
- Plasticity and Swelling of Coal (Committee D-5)
- Test Methods for Uniformity of Electrical Insulating Materials (Plates, Tubes, and Rods) (Committee D-9)
- Chemical Analysis of Rubber Products (Committee D-11)
- Tests (Physical, Chemical, Electrical) of Hard Rubber (Committee D-11)
- Sulfonated Detergents (Committee D-12)
- Tests of Plastics (Committee D-20)
- Recommended Practice for Dilatometric Analysis (Committee E-4)
- Felt (Committee D-13)
- Methods of Testing Rayon Staple and Spun Rayon Yarns (Committee D-13)

The Study of Methods of Capping Structural Clay Tile at Rensselaer Polytechnic Institute under the general direction of Committee C-15 on Manufactured Masonry Units is substantially completed but is not yet in shape for formal report to the committee and the Society.

The proposed Research on Correlation of Fundamental Properties of Paint Coatings and Service Tests (Committee D-1), referred to in Committee E-9's report last year, has been postponed until conditions in the paint industry are more propitious for the initiation of this project.

Committee E-9 still has under consideration the part that this Society might appropriately take in the proposed research on the standardization of pH measurements which has been suggested to be carried out under the general auspices of the National Bureau of Standards.

The reports of the standing committees this year contain much information on various research projects. The importance of the largest of these projects, namely, the study of corrosion resistance of wire and wire products, warrants special mention of the fact that the report[6] of Committee A-5 for this year gives the results of the referee tests made under the supervision of the National Bureau of Standards, defining the original characteristics of all wires on the exposure racks, and the first report of the Wire Inspection Committee giving the results of exposure at the eleven test sites for a period of approximately two years.

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[6] See p. 99.

Research Activities of Other Societies:

National Research Council.—The Society is represented on the Division of Engineering and Industrial Research of this Council by R. W. Crum and on the Highway Research Board of that Division by Prévost Hubbard, with F. E. Richart as alternate. A summary statement of the activities of the Research Council, including a statement of the work of the Highway Research Board, appears in *Science* for December 23 and 30, 1938, Vol. 88, Nos. 2295 and 2296. Reference should also be made to the annual Proceedings of the Highway Research Board covering the activities of the annual meeting of the Board held November 28 to December 2, 1938. At this meeting Mr. Hubbard presented a paper on "Adhesion of Asphalt to Aggregates in the Presence of Water." Many papers and reports presented at these meetings are of undoubted interest to a number of A.S.T.M. committees and the interlocking membership of those committees with the Highway Research Board practically assures that all such papers come promptly to the attention of the interested committees.

A.S.M.E. Research Committee on Mechanical Springs.—The Society is represented on this research committee by C. T. Edgerton. Fatigue tests on helical compression springs were continued during the year and the effect of surface finish on fatigue values is under investigation and will probably continue for some months. A survey of spring materials is expected to result in a compilation of a manual or current information on the physical properties of steels generally used for spring making. Mr. Edgerton presented a paper at a meeting of the committee describing the present status of helical spring design and relation of stresses to endurance of springs.

Engineering Foundation—Welding Research Committee.—The Society is represented on the Industrial Research Division of this committee by N. L. Mochel. This Division has for its objective the making of a survey of industrial welding research activities under way, contemplated, and desired, and providing organization to correlate these activities to the advantage of the welding industry. The Division as yet is largely in the formative stage of its work, although some projects are definitely under way. The division is organized into seven materials committees and six functional committees; the former deal with cast iron, carbon steels, low-alloy steels, high-alloy steels, aluminum alloys, copper alloys, and nickel alloys. The functional committees are on methods of testing, analysis of weld failures, weld stresses — causes and effects, nondestructive tests, resistance welding, and structural fatigue testing.

Our Society is directly interested in a number of these projects. Thus the Subcommittee on Carbon Steels is carrying out a study of the carbon-manganese ratio, a question that is of definite concern to Committee A-1 on Steel in connection with the subject of specifications for steels to be welded. Committees A-1 on Steel and A-10 on Iron-Chromium-Nickel Alloys are interested in the programs on the low- and high-alloy steels. The Subcommittee on Methods of Testing sponsored jointly with this Society a Symposium on Impact Testing[7] held at the 1938 annual meeting. The work of the Subcommittee on Non-Destructive Tests has been carefully coordinated with the Society's Committee E-7 on Radiographic Testing. A comprehensive testing program on structural fatigue testing is now under way. Other programs planned or under consideration are welding of aluminum alloys for pressure vessels and resistance welding of copper alloys, effect of wire temper and effect of arc length on the welding of nickel alloys, weld stresses related to pipe joints, and testing of spot welds.

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[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 21 (1938).

American Coordinating Committee on Corrosion:

As the outcome of conferences with representatives of other societies engaged in corrosion research, referred to in the report last year, the Society has joined with some seventeen other national societies and institutions in the formation of an American Coordinating Committee on Corrosion, which is to serve as a clearing house and coordinating agency for information on experience and work in progress in the field of corrosion and corrosion prevention. The names of the cooperating organizations and their representatives, together with an account of the organization meeting, appeared in the ASTM BULLETIN for March, 1939.

The formation of this committee will meet a need which both individuals and organizations have felt for a clearing house for information on corrosion work. The committee is now compiling a list of the names and addresses of those working in the field of corrosion in this country, together with information as to their special interests and their current programs of corrosion studies. Information is being sought respecting the names of individuals and organizations engaged in corrosion studies, the nature of such studies, and a record of experience and publications. The compilation of such information will serve many useful purposes both to individual workers in the field and to the various technical and industrial organizations that plan and carry out corrosion studies of many different kinds.

It is not the purpose of the Coordinating Committee to abstract the literature on corrosion.

The Coordinating Committee will of necessity proceed deliberately in the organization and extension of its work. One subcommittee is now engaged in examining all the information forms upon which the directory of research workers will be based, and another subcommittee is studying ways and means of permanent organization, which it is expected to effect at the next meeting of the A.C.C.C. to be held during this annual meeting of the Society.

Cooperative Corrosion Project with British Iron and Steel Institute:

It may be recalled from last year's report that through the interest of Committee A-5, ingot iron panels supplied by the Corrosion Committee of the British Iron and Steel Institute and companion panels of zinc supplied through the courtesy of the New Jersey Zinc Co. are exposed on test racks at Sandy Hook, N. J., State College, Pa., and Brunot Island, Pa. The losses in weight of these panels after one year's exposure have been determined and reported to the British Committee who in turn have submitted comparable data on losses of similar specimens at ten other stations scattered throughout the world. This work, including the preparation of the report, has been done by H. E. Smith, Materials Engineer; the National Bureau of Standards cooperated in cleaning and weighing the panels.

Administrative Matters:

With this meeting the term of R. W. Crum expires, and G. F. Jenks, Colonel, Ordance Department, Washington, D.C., has been appointed to succeed him.

The principal of the A.S.T.M. Research Fund is now $23,032.68. Since the report a year ago the principal was augmented by $1400 from the entrance fees for 1938 and profit on sale of investments amounting to $154.50.

The balance of income in the Research Fund on May 31, 1939, was $779.50, of which approximately $300 has been earmarked for several miscellaneous projects. The present annual available income from the principal of the Fund is approximately $680.

Respectfully submitted on behalf of the committee,

T. S. FULLER,
Chairman.

C. L. WARWICK,
Secretary.

REPORT OF COMMITTEE E-10

ON

STANDARDS

Committee E-10 on Standards held two meetings during the year: in Philadelphia, Pa., on August 25, 1938, and on December 14, 1938.

The committee records with sorrow the death on July 30, 1938, of J. B. Young who had served as a member of Committee E-10 since 1934. The Executive Committee of the Society appointed J. R. Townsend of the Bell Telephone Laboratories to fill Mr. Young's unexpired term (until 1940). R. P. Anderson of the American Petroleum Institute, and H. S. Mattimore of the Pennsylvania State Highway Department were reappointed to serve as members of the committee for a three-year term, expiring in 1941.

During the year Committee E-10, in cooperation with the officers of standing committees, has made a study of the Society's procedure with respect to the development of standards, with particular reference to the significance and status of tentative standards. This review has resulted in the following conclusions:

1. There is general agreement that the status of tentative standards should be continued since it is found helpful in the development of standards.

2. There should probably be no attempt to make any greater distinction between standards and tentative standards.

3. While some few considered that the term "provisional" would be more appropriate, in general the sentiment was in favor of retaining the term "tentative," especially since it has been in general use over a period of years and is now generally understood.

4. Two types of tentative standards are recognized: Those which are practically in final shape which would almost warrant immediate adoption as standard, and those which are in a very preliminary stage and represent the first attempt at arriving at a standard. With respect to the latter, it is suggested that in many instances these should preferably be published as information.

5. There is a very definite sentiment that committees should be urged to seek adoption as standard more promptly.

6. There is no general agreement as to whether there should be a definite time limit by which tentative standards must be adopted as standard or discontinued. A number of replies indicate that there should be such a limit of, say, one, two, or three years; others are just as positive that no time limit should be fixed, that the standing committees are in the best position to judge as to when the tentative standard is ready for adoption.

The replies resulted in a number of suggestions, as for example, that tentative standards should be revised only for essential changes, that any changes that are for clarification only should be deferred until the tentative standard is adopted and all editorial changes made at that time.

In the light of this review certain revisions in the Regulations Governing Standing Committees were prepared and submitted to the Executive Committee of the Society. Essentially these same revisions are now being balloted on in Committee E-5 on Standing Committees and are discussed in detail in the report of the Executive Committee being presented at this annual meeting of the Society.[1]

Certification.—The attention of Committee E-10 has been drawn to the diverse manner in which the matter of certification has been handled in various A.S.T.M. specifications. It is of course in only a relatively few cases that any certification clause has been found desirable by the standing committees sponsoring the specifications, for in the majority of cases certification is considered to be a contractual matter between the purchaser and seller and is so handled. There are, however, certain instances when material which has been manufactured and tested in large lots is shipped to a jobber for sale in small quantities, and in these instances certification is employed as a guarantee to the ultimate buyer. It is a question, however, whether the manner in which certification is now handled in certain of the specifications really accomplishes the purpose for which it was intended, and it was thought the wording now employed with reference to the offering of a certificate in lieu of making the tests required deserved careful review on the part of the sponsoring committee. Committee E-10 requested that the committees concerned, namely, A-1 on Steel, A-3 on Cast Iron, and A-7 on Malleable Iron Castings, give serious consideration to this entire subject to insure that there is really need for the inclusion of a certification clause and, if so, to the wording that is employed, a suggested wording having been prepared by Committee E-10. This is now receiving consideration in the committees concerned.

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[1] See p. 42.

The activities of Committee E-10 on Standards during the past year are set forth under the following heads: Review of A.S.T.M. standardization activities, consideration of new and revised standards, promotion and expansion of standardization activities, and relations with American Standards Association.

As in the previous year, a very considerable number of new tentative standards and revisions of existing standards and tentative standards have been submitted to Committee E-10 during the year for approval. For the most part these were considered at the August meeting of the committee.

REVIEW OF A.S.T.M. STANDARDIZATION ACTIVITIES

A general summary of the new and revised tentative standards submitted at the 1938 annual meeting was included in the August issue of the ASTM BULLETIN,[2] together with a review of the standardization work of the various committees, with statements concerning new standards in prospect. Much of the information, particularly with respect to standardization projects under development in committees, is furnished by the standing committees subsequent to the annual meeting and takes advantage of the fact that many committees plan their next year's work at committee meetings held during the annual meeting.

At the present writing, it is possible to make only a preliminary estimate in terms of new and revised standards of the volume of standardization work accomplished during the year and reported to the Society at this meeting. The reports of standing committees to be presented at the annual meeting include recommendations to the Society substantially as follows:

New tentative standards	62
Revisions of existing tentative standards	50
Tentative revisions of existing standards	22
Tentative standards recommended for adoption as standard	116
Revisions of existing standards recommended for adoption as standard	101
Standards and tentative standards withdrawn or replaced	57

There are at present 505 standards and 365 tentative standards of the

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[2] ASTM BULLETIN, No. 93, August, 1938, p. 28.

Society, making a total of 870, and if the above recommendations are approved this total will become 875.

CONSIDERATION OF NEW AND REVISED STANDARDS

Proposed new standards approved by Committee E-10 and published as tentative during the year are as follows:

Tentative Specifications for:

Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 - 38 T), submitted by Committee A-1 on Steel,

Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 209 - 38 T), submitted by Committee A-1,

Medium Carbon Seamless Steel Boiler and Superheater Tubes (A 210 - 38 T), submitted by Committee A-1,

Spiral Welded Steel or Iron Pipe (A 211 - 38 T), submitted by Committee A-1,

Electrolytic Cathode Copper (B 115 - 38 T), submitted by Committee B-2 on Non-Ferrous Metals and Alloys,

Hydraulic Hydrated Lime for Structural Purposes, submitted by Committee C-7 on Lime,

Asphalt Plank (D 517 - 38 T), submitted by Committee D-4 on Road and Paving Materials,

Sieves for Testing Purposes (Wire Cloth Sieves, Round-Hole and Square-Hole Screens or Sieves) (E 11 - 38 T), submitted by Committee E-1 on Methods of Testing,

Tentative Methods of:

Test for Clay Lumps in Aggregates (C 142 - 38 T), submitted by Committee C-9 on Concrete and Concrete Aggregates,

Test for Resistance to Light Checking and Cracking of Rubber Compounds (D 518 - 38 T), submitted by Committee D-11 on Rubber Products, and

Test for Fiber Length of Wool, submitted by Committee D-13 on Textile Materials.

Revisions of the following tentative standards and standards were accepted by Committee E-10:

Tentative Specifications for:

Seamless Steel Boiler Tubes for High-Pressure Service (A 192 - 38 T), submitted by Committee A-1 on Steel,

Carbon and Alloy-Steel Nuts for Bolts for High-Pressure and High-Temperature Service to 1100 F. (A 194 - 38 T), submitted by Committee A-1,

Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 38 T), submitted by Committee B-5 on Copper and Copper Alloys, Cast and Wrought,

Tentative Methods of:

Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 38 T), submitted by Committees C-9 on Concrete and Concrete Aggregates and D-4 on Road and Paving Materials,

Testing Films Deposited from Bituminous Emulsions (D 466 - 38 T), submitted by Committee D-8 on Bituminous Waterproofing and Roofing Materials,

Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 38 T), submitted by Committee D-9 on Electrical Insulating Materials,

Testing Pin-Type, Lime Glass Insulators (D 468 - 38 T), submitted by Committee D-9,

Testing Rubber Insulated Wire and Cable (D 470 - 38 T), submitted by Committee D-11 on Rubber Products,

Bend Testing for Ductility of Metals (E 16 - 38 T), submitted by Committee E-1 on Methods of Testing,

Sampling Ferro-Alloys (A 103 - 36 T), submitted by Committee E-3 on Chemical Analysis of Metals,

Chemical Analysis of Ferro-Alloys (A 104 - 36 T), submitted by Committee E-3.

Standard Specifications for:

Billet-Steel Concrete Reinforcement Bars (A 15 - 35), submitted by Committee A-1 on Steel,

Axle-Steel Concrete Reinforcement Bars (A 160 - 36), submitted by Committee A-1,

Electric-Fusion-Welded Steel Pipe (Sizes 30 in. and Over) (A 134 - 36), submitted by Committee A-1,

Electric-Fusion-Welded Steel Pipe (Sizes 8 in. to but not Including 30 in.) (A 139 - 36), submitted by Committee A-1,

Spiegeleisen (A 98 - 27), submitted by Committee A-9 on Ferro-Alloys,

Ferromanganese (A 99 - 27), submitted by Committee A-9,

Ferrosilicon (A 100 - 27), submitted by Committee A-9,

Ferrochromium (A 101 - 27), submitted by Committee A-9,
Ferrovanadium (A 102 - 27), submitted by Committee A-9,
Molybdedenum Salts and Compounds (A 146 - 34), submitted by Committee A-9,
Ferromolybdenum (A 132 - 34), and Low-Carbon Ferromolybdenum (A 145 - 34), submitted by Committee A-9,
Ferrotungsten (A 144 - 34), submitted by Committee A-9,
Phosphor Tin (B 51 - 27), submitted by Committee B-2 on Non-Ferrous Metals and Alloys,
Phosphor Copper (B 52 - 27), submitted by Committee B-2,
Silicon Copper (B 53 - 27), submitted by Committee B-2,
Brazing Solder (B 64 - 28), submitted by Committee B-2,
Aluminum-Bronze Castings (B 59 - 38), submitted by Committee B-5 on Copper and Copper Alloys, Cast and Wrought,
Clay Sewer Pipe (C 13 - 35), submitted by Committee C-4 on Clay Pipe,

Standard Methods of:

Test for Unit Weight of Aggregate for Concrete (C 29 - 27), submitted by Committee C-9 on Concrete and Concrete Aggregates,
Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (C 87 - 36), submitted by Committee C-9,
Chemical Analysis of Rubber Products (D 297 - 38), submitted by Committee D-11 on Rubber Products,
Test for Hardness of Rubber (D 314 - 34), submitted by Committee D-11,

Standard Grain Size Chart for:

Classification of Steels (E 19 - 33), submitted by Committee E-4 on Metallography, and

Standard Definitions of:

Terms Relating to Lime (C 51 - 28), submitted by Committee C-7 on Lime.

The withdrawal of the following standards and tentative standards which were replaced by new specifications and methods was approved by Committee E-10:

Standard Specifications for:

Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 - 36), recommended by Committee A-1 on Steel,
Sieves for Testing Purposes (E 11 - 26), and for Round-Hole Screens for Testing Purposes (E 17 - 36), recommended by Committee E-1 on Methods of Testing, and

Tentative Method of:

Test for Saponification Number of Electrical Insulating Oils (Modified Baader Method) (D 438 - 36 T), recommended by Committee D-9 on Electrical Insulating Materials.

PROMOTION AND EXPANSION OF STANDARDIZATION ACTIVITIES

In view of the various inquiries that the Society had received with respect to specifications for sulfur cements, principally in connection with their use as a jointing compound, Committee E-10 sponsored a conference on the subject in order to determine the amount of interest in the matter and the method in which it might best be handled, either by assignment to an existing standing committee or through the formation of a new committee. The conference was held in Philadelphia, Pa., on October 6, 1938, with H. S. Mattimore as chairman. The conference was of the opinion that standardization of sulfur cements deserves the interest of organized work and recommended that an A.S.T.M. committee be formed on this subject. The Executive Committee has approved this recommendation and it is expected that a committee on sulfur cements will be organized later in the year.

An inquiry from the Porcelain Enamel Institute as to the procedure to be followed in the establishment by the Society of standard test procedures has resulted in discussions with various interested companies as to whether this is a subject on which standardization work should be undertaken by the Society. Various tests are now employed in evaluating the properties of these enamels and much work has been carried out by the Porcelain Enamel Institute. There would appear to be some need for standardization with respect to test procedures, and more recently there has developed a need for standard specifications, since various agencies now find it necessary to develop specifications for the material in its different applications. The opinions so far expressed indicate, in general, considerable interest in the subject and a feeling that it would be of decided advantage to both manufacturers and consumers to have standard specifications and test methods in this field. Discussions on the subject are being continued.

The question of specifications for glues has been before Committee E-10 for a number of years. Since the gummed industries are now cooperating in the work of Committee D-6 on Paper and Paper Products and may wish work to be undertaken on glue, Committee E-10 has decided to defer consideration of this matter pending the receipt of a request from Committee D-6 for such specifications.

The question of having work undertaken on standards in the field of industrial chemicals has been discussed with the Manufacturing Chemists' Association. That association, after giving careful consideration to the subject, is of the opinion that, since specifications for industrial chemicals vary with the use, the possibility of a single specification applying, for example, to caustic soda or sulfuric acid usable for different consuming trades is not feasible, and further, that there does not appear to be any genuine need for a program to develop specifications for each use of each industrial chemical.

RELATIONS WITH AMERICAN STANDARDS ASSOCIATION

Standards Submitted Under Proprietary Method.—The proprietary method for submitting revisions of standards approved by the American Standards Association is particularly appropriate for a large number of A.S.T.M. standards. Under this procedure revisions of the following American standards have been approved during the year by the ASA:

Standard Specifications for:

- Structural Rivet Steel (A 141 - 38; ASA G21—1938),
- Bronze Trolley Wire (B 9 - 38; ASA H22.1—1938),
- Copper Trolley Wire (B 47 - 38; ASA H22.2—1938),
- Basic Carbonate White Lead (D 81 - 38; ASA K23—1938), and

Standard General Methods of:

- Testing Woven Textile Fabrics (D 39 - 38; ASA L5-1938).

Standards Submitted Under Sectional Committee Procedure.—Reports were received from several of the sectional committees for which the Society is sponsor, submitting standards to the ASA for approval. These reports have been transmitted to that association and the following standards have been approved during the year as American standards, with the exception of one which has been approved as American tentative standard, as indicated:

On the Recommendation of Sectional Committee B36 on Standardization of Dimensions and Materials of Wrought-Iron and Wrought-Steel Pipe and Tubing:

- Specifications for Welded Wrought-Iron Pipe (A 72 - 38; ASA B36.2—1939), and
- Specifications for Electric-Fusion-Welded Steel Pipe for High-Temperature and High-Pressure Service (A 155 - 36; ASA B36.11—1939).

On the Recommendation of Sectional Committee M20 on Classification of Coals:

Specifications for Classification of Coals by Rank (D 388 - 38; ASA M20.1—1938), and

Method for Designating the Size of Coal from Its Screen Analysis (D 431 - 38; ASA M20.3—1938).

On the Recommendation of Sectional Committee Z11 on Petroleum Products and Lubricants:

Method of Test for Distillation of Gasoline, Naphtha, Kerosine and Similar Petroleum Products (D 86 - 38; ASA Z11.10—1938),

Method of Test for Viscosity by Means of the Saybolt Viscosimeter (D 88 - 38; ASA Z11.2 —1938),

Method of Test for Color of Refined Petroleum Oil by Means of Saybolt Chromometer (D 156 - 38; ASA Z11.35—1938),

Method of Test for Distillation of Gas Oil and Similar Distillate Fuel Oils (D 158 - 38; ASA Z11.26—1938), and

Tentative Method of Test for Knock Characteristics of Motor Fuels (D 357 - 38 T; ASA Z11.37—1938), approved as American tentative standard.

Sectional Committees Organized.—The following sectional committees of interest to the A.S.T.M. have been organized during the past year under the procedure of the American Standards Association and the Society has accordingly appointed representatives thereon:

Sectional Committee A56 on Building Code Requirements for Excavations and Foundations, represented by W. S. Housel of the University of Michigan,

Sectional Committee A59 on Building Code Requirements for Reinforced Gypsum Concrete, represented by W. J. Krefeld of Columbia University,

Sectional Committee A62 on Coordination of Dimensions of Building Materials and Equipment, represented by Theodore I. Coe of the American Institute of Architects,

Sectional Committee D9 on Standardization in the Field of Aeronautics, represented by C. B. Veal of the Society of Automotive Engineers, with R. P. Anderson of the American Petroleum Institute as alternate, and

Sectional Committee Z38 on Standardization in the Field of Photography, represented by L. V. Foster of Bausch & Lomb Optical Co., with H. E. Seemann of Eastman Kodak Co. as alternate.

In order to coordinate the work of Committee D-9 on Electrical Insulating Materials and Sectional Committee C29 on Insulators for Electric Power Lines, the Society has requested and has been granted representation on the latter committee, with the following serving as A.S.T.M. representatives: U. E. Bowes, Merrill DeMerit, V. F. Hammel, and H. A. Wadman.

Respectfully submitted on behalf of the committee,

CLOYD M. CHAPMAN,
Chairman.

C. L. WARWICK,
Ex-officio Secretary.

TECHNICAL PAPERS

With Discussions

STRESS, STRAIN, AND STRUCTURAL DAMAGE

Edgar Marburg Lecture[1]

By H. F. Moore[2]

I wish at the very beginning to make two general statements of my viewpoint and my general purpose in this lecture.

I am a testing engineer, whose work has been very largely with metals. This influences the viewpoint, and especially the illustrations used in this lecture. Metallurgists, chemists, physicists, and workers with non-metallic materials may quite justly criticize this presentation as not giving due emphasis to the subject matter of their fields. May I ask such to try the plan which I have found effective when listening to or reading a dreary sermon, or one with which I disagree. I try not to get indignant, but rather to consider the question "How did that preacher get that way?" When I am successful in making my rather wayward mind behave thus, there usually develops a surprising amount of sympathy for the "preacher chap," the net result is benefit rather than a grouch.

Then I am going to try to give pictures of the forest rather than close-ups of individual trees,—cartoons rather than detail photographs. This means that there may be many fine points overlooked and perhaps some too broad generalizations made. I hope not but I fear so.

The members of the American Society for Testing Materials resemble the materials of construction in that they are not homogeneous. There are various breeds of engineers, also pure physicists, pure chemists, metallurgists and timber experts who are most of these things and biologists to boot,—the list might go on much further. There are producers and consumers, salesmen, technicians and even a few executives. The only type of individual I have not in the A.S.T.M. is the "yes man."

Now this address should be so planned as to arouse some interest in all these people, and I am going to try the rather dangerous experiment of making a few remarks in what I hope is a philosophical vein. The pure philosopher and the pure scientist have as a common goal the discovery of truth—impersonal truth free from all contagion of "wishful thinking," and, let us hope, free from that less recognized but equally dangerous defect, wishful observation. In their search for impersonal truth, scientists and philosophers have usually found it inexpedient to pay much attention to questions of *value* or *significance* of the truth discovered, although, among the philosophers at least, this attitude shows signs of changing. But we of the A.S.T.M. who have to serve producers and consumers of materials cannot possibly neglect questions of value and significance. It is not infrequently true that such questions as "What is the significance of these test results?" and "What is the value of this quality of a material in service?" are almost, if not quite, as important as is the question, "What is the truth about the properties of the material?"

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[1] Read on June 28, 1939, before the Annual Meeting of the American Society for Testing Materials, Atlantic City, N. J.

[2] Research Professor of Engineering Materials, University of Illinois, Urbana, Ill.

In planning the shape and size of structural and machine members so that they will function without mechanical failure, the designer has to consider the problem of materials from several viewpoints of which three may be considered here: (1) what are the magnitudes, directions, length of time and frequency of application of the loads which the part must carry, and how long a "life" must the part have for satisfactory service?; (2) what are the intensities of internal force (stresses), the deformations (strains), and the energy represented by the stress-strain relation which must be resisted without injury; and (3) what are the significant resisting properties of various available materials for the part, and what is their quantitative value?

The answer to the first question demands a study of the conditions of service, sometimes involving considerable statistical field study or experiment, and always involving considerable uncertainty. The answer to the second question involves computations generally based on the common formulas of the mechanics of materials and involving the acceptance as "true" for actual materials of the assumptions of those formulas—for all formulas involve assumptions. However, the determination of stresses, strains, and internal energies does not give any information as to the destructive effect produced on any given material. So then the third question must be answered on the basis of tests of material, either laboratory tests or service tests. Now what is the significance of different laboratory tests of materials for a given structural or machine part. For example, what are the significant laboratory tests of material for a connecting rod for a Diesel engine; test of tensile strength, of yield strength, of ductility, strength under long-continued steady load, strength under load repeated millions of times, resistance to fracture under one rapidly applied load (impact), and so on.

Taking another view of the A.S.T.M., not merely as an organization which began its career in 1898, but as an outgrowth of the thoughts and activities of people who, before the dawn of recorded history, were using materials and judging their fitness, it seems in order to comment very briefly on the development of our ideas about material, on the ever increasing complexity of our problems, and on the growing use of quantitative measures of value as a basis for choosing materials for our structures and machines.

Legends of metallurgical methods in medieval times are known, and an examination of certain ancient structures, notably Gothic cathedrals and the dimensions of beams of the ancient naval storehouse at Piraeus the port of Athens, indicate that by some means unknown to us the architects proportioned arches and beams much as would the present-day structural engineer, if we used the same materials. But we have no clear light on the proceedings of the ancient and medieval societies for testing materials (if such there were) until we come to that great figure in the history of experimental study, Galileo, and consider his development of the theory of the strength of beams.

His discourse on beams was published about twenty years after the Pilgrims landed at Plymouth and about forty years before the capital city of the A.S.T.M. was founded by William Penn. Briefly his assumptions, expressed in modern terms, were as follows: (1) fracture is the index of structural damage to the material, and would be determined by tensile strength (Galileo has left us very little information as to the details of any of his experimental work on materials), (2) the moment of the resisting forces inside the beam at any section balances the bending moment of the outside forces to one side of that section, (3) the forces inside the beam "pivoted" about the compression edge of the beam, and (4) the beam remained absolutely rigid until fracture, and consequently the intensity of internal force (stress) was *uniform* over any cross-section of the beam and the total internal force might be replaced by a resultant force acting at the center of gravity of the cross-section, with an "arm" equal to the distance from that center of gravity to the compression edge.

The supposition that internal moment balances external moment to one side of a section we still use. We recognize other indices of structural damage besides fracture, and we have found that the assumption of absolute rigidity and uniform stress distribution is not true. However let us not judge Galileo harshly; it seems highly probable that our present-day assumptions are not rigidly true either, and for well over a century Galileo's analysis worked very well for rectangular beams of wood and stone.

Galileo's simple index of structural damage, tensile strength, is not, however, adequate for us today. So here may I offer a definition of structural damage, not for approval by the Committee on Nomenclature and Definitions, but for the use of hearers and readers of this lecture.

> A structural or machine part suffers structural damage when, due to fracture or deformation, it ceases to function satisfactorily.

Before going on to discuss various types of structural damage I wish to consider a very common, although usually tacit, assumption made in studying structural and machine parts, namely, that when the critical stress for structural damage (as determined by a simple laboratory test of the material) is exceeded *at any point* in a part then that part has suffered structural damage. I shall discuss this assumption by describing an experiment which at the University of Illinois we have our advanced students in materials laboratory perform. In this test, permanent deformation is recognized as the type of structural damage considered, and permanent deformation is taken as measured by the amount of deviation in strain from that given by Hooke's law (strain proportional to stress) as load is applied. This measure of permanent set is approximate but reliable—at least for the common metals.

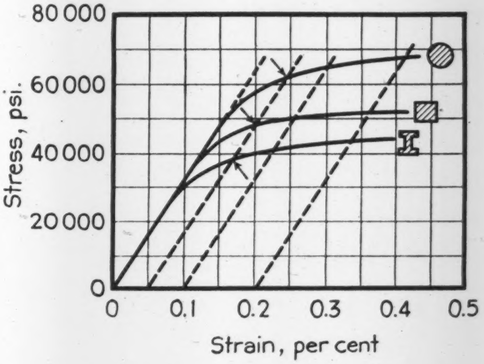

FIG. 1.—Stress-Strain Diagrams and Yield Strengths of Different Shapes of Steel Beams Tested in Flexure.

The student is given three pieces of structural steel all cut from the same bar, 1 in. square, and all the same length. One of the pieces is left square, a second is turned to a circular section, and the third is milled to I-beam shape. Each bar is then placed on the weighing table of a testing machine and a flexural test made in which load and deflection are measured. Below the limit of elastic strength, stress in the extreme fibers of the specimen is proportional to load, and deflection is proportional to strain. Therefore a stress-strain diagram for the test of each bar can be drawn as shown in Fig. 1. The students are directed to determine the elastic strength of the steel from the test results for the three bars, and the elastic strength is set at an arbitrary limit of structural damage located by a permanent set of, say, 0.05 per cent strain, or what is approximately the same thing, an offset of 0.05 per cent from the straight-line part of the stress-strain diagram, as is shown in Fig. 1. The student usually expects, as I did the first time I tried the experiment, that the three specimens would give approximately equal values for elastic strength, but they do not, as can be seen from Fig. 1. In the case of the round bar the "most stressed fiber" covers a very small portion of the area of the cross-section, and it is "backed up" by understressed fibers close at hand; for the square bar a zone of most stressed fibers extends clear across the edge and fewer nearby understressed fibers are available for help. In the case of the I-section bar there are relatively few understressed fibers available to help the most stressed fibers.

This experiment is designed to show the students that the actual resistance of a structural or machine part to structural damage by permanent deformation depends not alone on the maximum stress, but also on the area affected by that stress, by the distance and amount of understressed material to which some of the overstress can be shifted, and on the ductility of the material which permits slight permanent set without fracture.

Now actually in all materials, at least all the common structural materials, there are always minute areas of high stress; that is, the material is by no means perfectly homogeneous. Small inelastic deformations cut down the "peaks" of these localized high stresses. I doubt very much whether there are any machine parts in service which, over microscopic areas here and there, have not been stressed beyond the elastic range (if there is any range of absolute elastic action). I further believe that if it were not for this relief of stress by localized inelastic action it would be very doubtful whether our structural and machine parts would stand up in service. Carefully dried plaster of Paris shows very little inelastic action right up to fracture, and even if a very strong plaster of Paris could be developed no one would dare to make a crane hook out of it, or out of ordinary gray cast iron for that matter.

I beg your indulgence while I discuss this simple test somewhat further. The resistance of a beam to structural damage by permanent distortion depends to a considerable degree on the behavior of its material when the action is no longer perfectly elastic. That is our ordinary stress-strain formulas—the whole mathematical theory of elasticity, in fact—is based on the behavior of an ideal material which would not behave quite as our actual materials do, and which does not fully explain the results of our simple flexure test of steel bars. The ideal material assumed by the theory of elasticity is perfectly homogeneous and isotropic (equally deformable in all directions), and Hooke's law is assumed to hold. A glance through the microscope disposes of the question of homogeneity of timber, concrete, brick, and the ordinary structural metals. Tests of single crystals, or of specimens of wood dispose of the assumption of isotropy. Hooke's law is a very close approximation up to some more or less definite limiting stress.

If one feels in the mood to indulge in a bit of technological muck raking he may dismiss the attempt to apply the mathematical theory of elasticity to actual materials of construction with the remark that *when so applied* the theory is based on three assumptions, two of which are false and the third of which is an empirical approximation. Now the materials testers of all varieties have not adopted this attitude, and I wish to point out a comparison between their attitude and that of some legal, and I regret to say, some religious groups when faced with a similar attack on some of their fundamental assumptions. I know of no record of the proclaimers of the non-infallibility of the theory of elasticity being confined in the stocks, ducked in the town pond, or even being thrown out of the A.S.T.M. for their heresy. There have been discussions, a few fairly acrimonious ones, but we materials testers have refused to be stampeded, even by a really very revolutionary idea. The common reaction to such statements as I have made has been the inelegant, but highly pertinent question "so what?", and when that question is considered the results are not so very alarming.

We can regard all our structural materials as having a "statistical homogeneity," and to illustrate what I mean by that phrase may I choose as an intellectual guinea pig for discussion Committee C-9 on Concrete and Concrete Aggregates. That committee is composed of a large number of diverse individuals, with wide variations of opinion, and yet as a whole follows a consistent and unified policy.

So with our materials of construction. Structural damage to a material, at least under static load, rarely, if ever, takes place until an appreciable volume of material is involved—a volume comprising thousands of grains or of fibers, hundreds of thousands of space lattice cells, and millions of atoms. That makes it seem as if statistical methods might be useful and reliable guides, and since no better theory has as yet been developed than the mathematical theory of elasticity, and since it may be regarded as statistically true when applied to actual materials, we propose to retain it and use it until a better method has been demonstrated, and shown to be usable.

I believe this attitude is typical of the applied scientist. I believe it to be an attitude not only justifiable but praiseworthy in our reactions to the actual problems of materials and of life. I recognize the danger of becoming too insensitive to better fundamental assumptions and the theories built on them, but after all that is considered, I respectfully call the attention of the traditional learned professions to this attitude and humbly suggest that it is worthy of consideration. (I except the medical profession; they are really applied scientists, and this is an old story to them.) I hope as I proceed with this lecture to show how our theory of elasticity may be regarded as within wide limits a safe guide to the materials engineer, and how by relatively slight modifications it can be made to serve our present-day needs.

STRUCTURAL DAMAGE BY ELASTIC DEFORMATION

I now wish to discuss four types of structural damage due to mechanical causes: (1) elastic deformation, (2) damage by inelastic action, (3) fracture, and (4) damage by continuing deformation or "creep." These are by no means the only kinds of structural damage; such important types as corrosion and wear are not mentioned. However, the limitations of time and the speaker's knowledge make it seem advisable to limit our discussion to these four types of damage.

Structural damage by elastic deformation may be illustrated by considering the case of a steam turbine rotating disk with an ineffective shrink fit on the turbine shaft. Elastic deformation due to centrifugal force may make the disk loose on the shaft, and such looseness would be the primary structural damage. Even more serious secondary damage might follow. The looseness on the shaft may allow lateral vibrations to be set up followed by breaking of turbine blades attached to the disk as they strike against the nozzles through which steam comes.

In passing, it may be noted that in the case of the turbine disk the looseness on the shaft would in itself be regarded as structural damage, even though the deformation was within the range of elastic strength of the metal and the disk again became tight on the shaft when rotation ceased. The secondary damage due to breaking of blades and injury to nozzles is even more serious. However, it is sometimes possible to cause structural damage to a member by *elastic* deformation without injuring the material.

In spite of the non-homogeneity and non-isotropy of actual materials the theory of elasticity is a very satisfactory guide indeed for designing against structural damage by elastic deformation. Viewed microscopically material is not homogeneous, but viewed macroscopically a structural or machine part under elastic stress behaves as if it were homogeneous within the tolerances of careful machine work. The material is "statistically" homogeneous. If, here and there, there is an "outlaw" crystalline grain or fiber which is a "conscientious objector" to the general elastic behavior, the effect on the behavior of the whole part is negligible. For elastic deformation we may use the mathematical theory of elasticity, perhaps not with quite the degree of confidence as we have in astronomical calculations, but with a very high degree of confidence indeed.

STRUCTURAL DAMAGE BY INELASTIC ACTION

Probably the type of structural damage most feared by designers and builders of metal structures is failure of the elastic strength of the material with consequent permanent distortion. Appreciable permanent distortion itself usually constitutes structural damage. Sagging rafters and beams certainly damage the appearance and sales value of a house, unless it is so old that even its defects take on a romantic beauty—usually more appreciated by artists than by the dwellers in the building. We have records of this sort of structural damage to at least one ancient building, and several cathedrals have struts "jacking up" sagging arches.

The secondary effects of failure of elastic strength are frequently more serious than the primary. Sagging floor beams mean cracked and falling plaster from the ceiling below. Still more serious is the effect of failure of elastic strength of the metal in steel columns of medium length. Very long columns first buckle by *elastic* deformation and, by limiting their lateral bending, it is possible to load a long, thin column to its ultimate load without injuring the material in it. Buckling under compression depends on lateral *stiffness.* Now if any considerable volume of the steel in a medium-length column is compressed beyond its elastic strength its stiffness is greatly reduced, the stiffness of the column as a whole is appreciably reduced, and there is danger of lateral buckling of the column followed by disastrous collapse.

Structural damage by inelastic action may also consist of a redistribution of stress. In the flexure test described such redistribution was on the whole beneficial, but in a complex structure redistribution may be injurious. For example, in a welded or riveted truss failure of elastic strength in a strut may cause serious flexural stresses in joints or in members not designed for flexure.

Of course in machine tool parts and delicate measuring instruments even a very small permanent distortion may constitute serious damage.

When the metallurgist poked his inquisitive microscope into the field of the materials of construction one of the early things he did was to give us a new picture of the mechanism of failure of elastic strength. First of all he showed us that metal was not homogeneous, but rather was an aggregate of crystalline grains; then later he showed how, when the elastic strength of any grain fails there appear "slip lines" (or "slip bands") across the grain as shown in Fig. 2. At first these slip lines are seen in a few scattered grains, then as stress increases they multiply until whole areas in the field of the microscope are black with them.

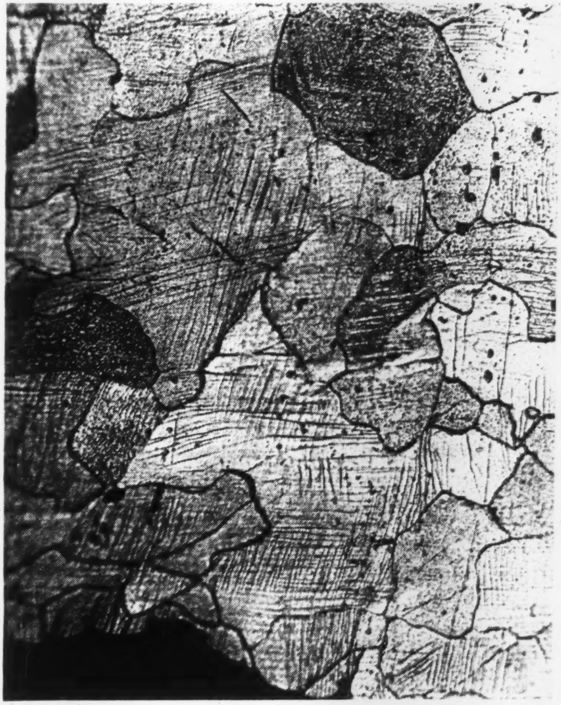

FIG. 2.—Slip Lines in Ingot Iron (× 390).
Micrograph by Tibor Ver.

Later the X-ray spectrograph has given us a picture of these slip lines as traces of definite atomic planes within the crystalline grain.[3] The point I wish to make is that the metallurgical microscope and the X-ray diffraction pattern have given us a picture of the failure of elastic strength of a piece of metal as the aggregate of a large number of localized failures of individual crystalline grains along planes of atomic weakness, and have shown that the failure is essentially a shearing failure.

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[3] For an excellent discussion of the mechanism of slip within crystalline grains see the 1933 Marburg Lecture by H. J. Gough, "Crystalline Structure in Relation to Failure of Metals—Especially by Fatigue," *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 3 (1933).

The failure of elastic strength of a single crystalline grain in a structural or machine part rarely is to be regarded as structural damage to the part as a whole. Just how many grains must fail and how close together they must be to cause appreciable damage is a matter for empirical judgment based on experience. In some of the A.S.T.M. Standards the limiting distortion which shall be regarded as causing structural damage is set at some definite permanent set,—a permanent set of 0.2 per cent of any given gage length is sometimes specified.

In setting an arbitrary limit of permanent set to locate the beginning of structural damage by failure of elastic strength we are recognizing the fact that slip within grains must be widespread throughout a structural or machine part before damage is done. We are again assuming that our non-homogeneous material may be considered as "statistically" homogeneous. This has proven satisfactory in considering failure of elastic strength, although this "statistical" reasoning does not seem quite so reliable as it does when used in considering elastic deformations.

In discussing failure of the elastic strength of materials I have confined my remarks to the behavior of metals. Relatively little microscopic study has been made on non-crystalline materials and of non-metals in general: glass, stone, burnt clay products, concrete, the plastics (including rubber), rope fibers, to mention a few cases. Some work has been done on timber, but the study of the mechanism of failure of elastic strength of non-metals seems to me a most promising field of research.

STRUCTURAL DAMAGE BY FRACTURE

Perhaps the most dramatic type of structural damage is fracture. Damage by fracture has been recognized ever since men felled trees across streams or used vegetable fibers to carry tensile stress. We will leave to the anthropologists the question whether there was a Simian Society for Testing Materials, with a Committee Q-1 on Vegetable Fibers.

It seems convenient to consider fracture under three headings: (1) fracture under short-time steady load, (2) fracture under long-time steady load, and (3) fracture under repeated stress.

For specimens of ductile materials, tested in the laboratory, fracture under steady load usually occurs after much inelastic action, marked by elongation and "necking down" of cross-section. This is rarely the case in the fracture of structural or machine members in service. These service fractures, even under steady load, usually occur at some discontinuity in the part—a hole, a keyway, a screw thread—and the amount of permanent stretch is much less than that found in tests of carefully shaped specimens. For brittle materials fracture occurs with very little distortion, and the effect of sudden changes of section are very marked indeed. For ductile materials under steady load, holes, keyways, screw threads, etc, while they reduce the ductility of a structural or machine part, reduce the strength very little, if any; in fact they sometimes increase tensile strength due to the restriction of lateral contraction. However, for parts made of brittle material the effect of discontinuities in cross-section is to reduce the tensile strength markedly.

It is natural to think of fractures occurring in the manner described by Oliver Wendell Holmes in his poem on the choice of materials for and the service record of the "wonderful one-hoss shay," whose failure occurred

> "all at once and nothing first,
> Just as bubbles do as they burst."

But the high-speed motion picture camera shows that neither bubbles nor pieces of wood or metal fracture "all at once." They fracture progressively, but so rapidly that the eye can rarely follow the progress of the spreading crack.

The beginning of fracture is a highly localized phenomenon. Just when and how a destructive crack starts is as yet an unsettled question. The changes of pattern given by an X-ray spectrograph as stress increases, or is repeated, seem to picture the breaking up of crystalline grains of metal into "crystallites"—units larger than a space lattice cell, but smaller than a crystalline grain. Somewhere in this region between the atomic size range and the microscopic size range, fracture, of metals at least, seems to start. When a crack can be distinguished under a magnification of, say, 200 times it is fairly certain that a destructive spreading fracture is well on its way.

Fracture by a spreading crack under repeated load has come to have the misleading name "fatigue." An outstanding characteristic of a "fatigue" crack is that it develops with very little distortion of the part as a whole. It seems as if the ductility of the material had been destroyed. However test specimens cut from material as near the crack as possible show no loss of elongation or reduction of area. It was noted that under steady load applied for a short time tensile strength of ductile metal was not much reduced by holes, notches, screw threads and the like. However, under repeated stress all this is changed and any discontinuity, even a slight roughness of surface may serve as a nucleus for a crack, and, once started, the crack itself is a location of very severe intensification of stress, and thus a crack tends to be self propagating under repeated stress, especially under reversed stress. For some metals this tendency is partly offset by the strengthening of the metal at the root of the crack by plastic action (cold work), but this strengthening is accompanied by diminution of ductility and a lessening of the capacity of the metal to cut down the peak of further localized stress without cracking.

This conflict of beneficial and injurious factors under repeated stress gives an almost theological aspect to the phenomena of repeated stress—one remembers the legends of a good angel fighting with the devil for the soul of a poor sinner. Perhaps the analogy of bacterial infection is less dangerous to use. Repeated stresses, intensified at many minute locations in a structural or machine part, keep trying to crack the material, just as the thousands of disease germs in our bodies keep trying to break down our resistance. Under attack the body automatically calls its reserve resisting powers into action, and the metal "stiffens up" through cold work. But, alas, the body's resisting powers are not inexhaustible, and the stiffening up by cold work uses up the ductility of the metal in the immediate vicinity of the crack. Under normal conditions the body preserves the balance of health, keeping the bacterial hosts in check, and the material stops the incipient crack without exhausting ductility in its vicinity. Under increase of bacterial attack or decrease of bodily resistance the bacterial host may conquer, so under increase of magnitude or number of repeated stresses the material may succumb.

The metallographic microscope shows fatigue cracks starting along slip lines, although only a small percentage of slip lines develop into cracks. Progressive cracks, once started, soon tend to take a direction at right angles to the maximum tensile stress in the region affected.

Repeated stress tests show the localized nature of fracture far more clearly than do tests under steady load. We can reason about materials of construction as though they were homogeneous and draw very reliable conclusions about the behavior of materials under elastic strain, we can draw quite fairly reliable conclusions about the failure of elastic strength of structural and machine parts, but when we come to fracture under repeated stress we find it necessary to modify our usual formulas, or the constants we use in them. Statistical reasoning does well enough for distortions involving macroscopic volumes of material but it is not so reliable for microscopic volumes of material, and it is in a microscopic, or, perhaps sub-microscopic, volume of material that a spreading crack usually starts. Still, we have no better formulas for use, and the modification of our ordinary formulas for stress and strain by the use of shape factors, size factors, and factors of sensitivity to "stress raisers" (holes, notches, and the like) seems to be our best course *at present.*

Among other factors, repeated-stress tests have shown that the stress history of a material affects its resistance to cracking,—and its elastic strength too, for that matter. If metal is repeatedly understressed, or overstressed for a few times, it may be strengthened. If it is overstressed until a crack starts—and unfortunately we do not know just when a crack starts—the resistance to further spread of the crack may be diminished, sometimes as much as 50 per cent.

Taking it altogether, the study of repeated stress and its effects on the strength of materials has stirred up what may be called a medium-sized revolution in our thinking about the materials of construction.

STRUCTURAL DAMAGE BY CONTINUING DEFORMATION (CREEP)

A type of structural damage which produces distortion much as inelastic action does, but whose nature is probably quite different, is "creep," which may be defined, for this lecture at least, as distortion which under steady load continues to increase with time. Examples of creep are the continued bending of a glass rod under a steady load, the slow month-by-month expansion of lead pipes under internal pressure, the slow flow of concrete and some natural stones under steady compression, and, most important of all, the slow creep of metals at elevated temperatures.

For each material, at least for the metals so far studied, there seems to be a more or less well defined temperature below which creep is unimportant as a cause of structural damage and above which it is important. Under inelastic action below this critical temperature, cold work stiffens the metal and stops distortion; above this critical temperature (more or less well defined) the metal acts somewhat as if it were a very viscous liquid. However, the rate of creep of a flange bolt or a lead cable sheathing is not, in general, directly proportional to stress, as is the case for viscous flow. This may be explained by the hypothesis that creep, like inelastic distortion below the creep temperature, occurs in many localized microscopic areas, and that in any such area the flow of metal is that of a viscous liquid. If stress is increased the resistance of the metal to creep is diminished, and if temperature is increased the atomic energy tending to cause creep is increased, and not only is the creep rate increased at those locations where it is already occurring, but creep starts at new locations. If this be the case, then under constant temperature the *total creep* of a bolt or a pipe would increase more rapidly than would the stress.

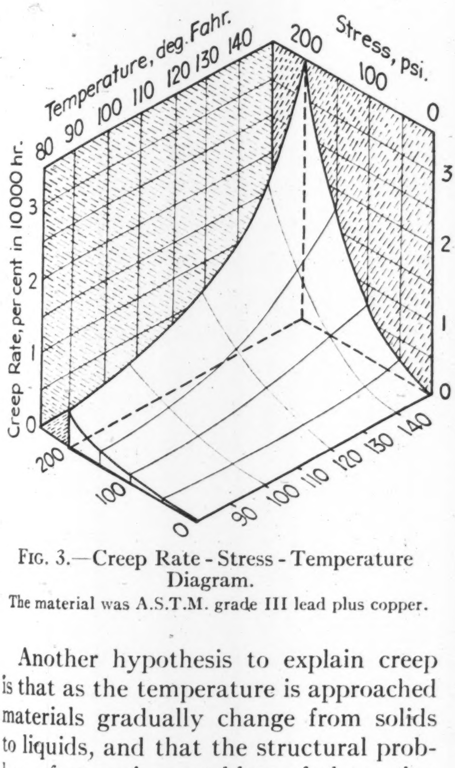


FIG. 3.—Creep Rate - Stress - Temperature Diagram.

The material was A.S.T.M. grade III lead plus copper.

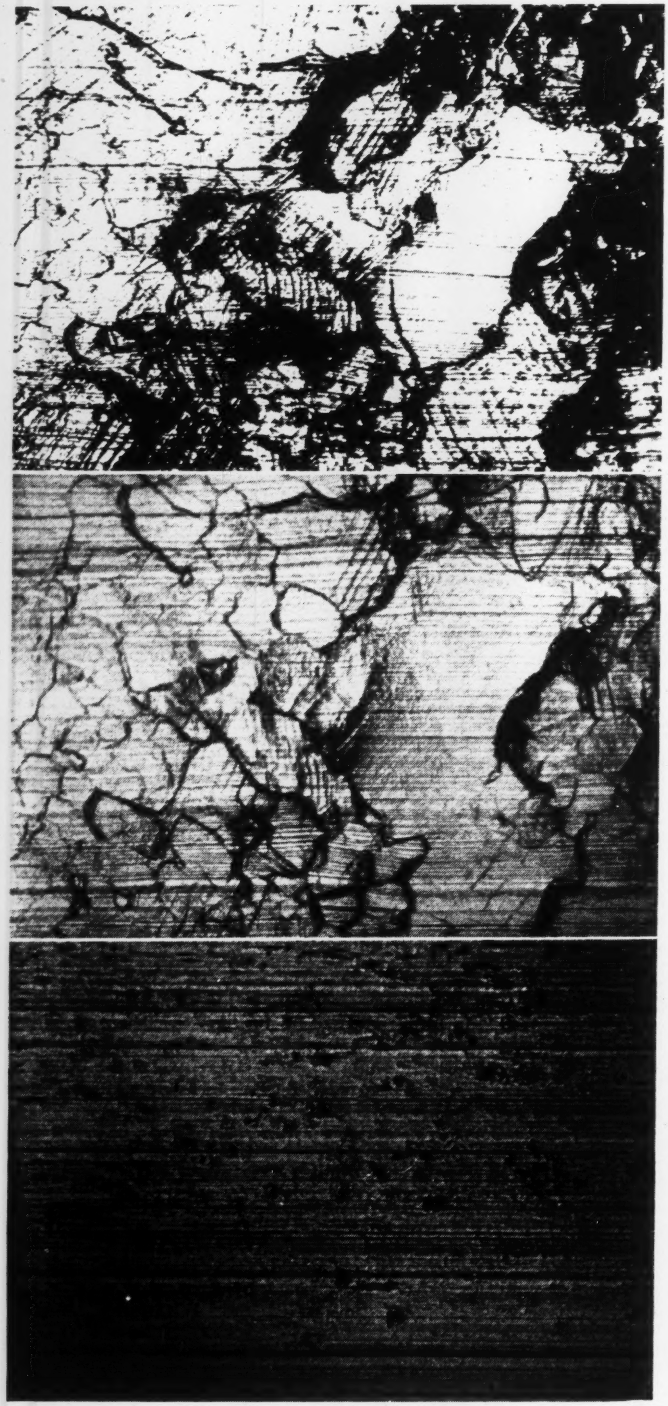
Another hypothesis to explain creep is that as the temperature is approached materials gradually change from solids to liquids, and that the structural problem of creep is a problem of the action of what might be called a quasi-viscous material.

Continuing creep in metals or concrete is a direct cause of structural damage. When flange bolts in a steam line begin to creep, leakage soon appears; when lead sheathing on electric cables creeps insulation voids are sometimes caused inside the sheathing, and insulation troubles appear; when the concrete in a column creeps stress is transferred from the concrete to any longitudinal steel rods, sometimes to the extent of stressing the rods to their yield strength. Temperature is a factor of major importance in creep phenomena. As noted, below a more or less well defined temperature the creep of a material is negligible, but above that temperature the creep rate increases very rapidly with temperature. This is illustrated in Fig. 3. It may be noted that concrete, lead, tin, and zinc all show appreciable creep at ordinary room temperatures.

In evaluating the structural damage due to distortion caused by creep, the material may be regarded as a "statistically" homogeneous body. Creep seems to be a localized phenomenon, but the locations where it occurs are scattered throughout the metal of a structural or machine part. This reasoning does not necessarily apply to *fracture* following creep, which will be discussed later. Of course, we cannot use the theory of *elasticity* as we are dealing with *flow*.

In non-creeping inelastic action of metals the mechanism of distortion seems to be a slipping along planes of atomic weakness within crystalline grains. This slipping is shown by the appearance of slip lines. In the case of creep this mechanism is shown, but, for lead at least, the metallurgical microscope shows evidence of displacement and rotation of crystalline grains as a whole. This is shown in Fig. 4.

Creep, if continued for a sufficient time, will lead to fracture by means of a spreading crack, somewhat like a fatigue crack. Figure 5 shows a typical creep-time diagram for a metal. The diagram



(*a*) Unstressed. (*b*) After 48 hr. under a tensile stress of 800 psi. (*c*) After 96 hr. under a tensile stress of 800 psi.

FIG. 4.—Micrographs Showing Rotation of Grains and Development of Slip Bands During Creep (× 200).

Specimen, A.S.T.M. grade III lead. All micrographs taken at same location on specimen. Specimen unetched. Micrograph by B. B. Betty.

may be divided somewhat arbitrarily into three stages. In the first stage there is a diminution of creep rate (slope of creep-time line). Probably this stage is largely taken up in "evening up" stress on the specimen, or piece of metal. Remember that it is very difficult to grip and load even a laboratory tension specimen so that there is no appreciable variation in the stress across its critical section.

In the second stage the metal "settles down" to an approximately constant rate of creep. The third stage probably begins when "necking down" takes place at some section of localized weakness. Then creep is greatly accelerated and soon a spreading crack appears. Fracture under creep, like fracture under repeated stress, is a highly localized phenomenon, and localized defects assume a distinctly greater importance than when the danger of structural damage arises from non-fracturing distortion.

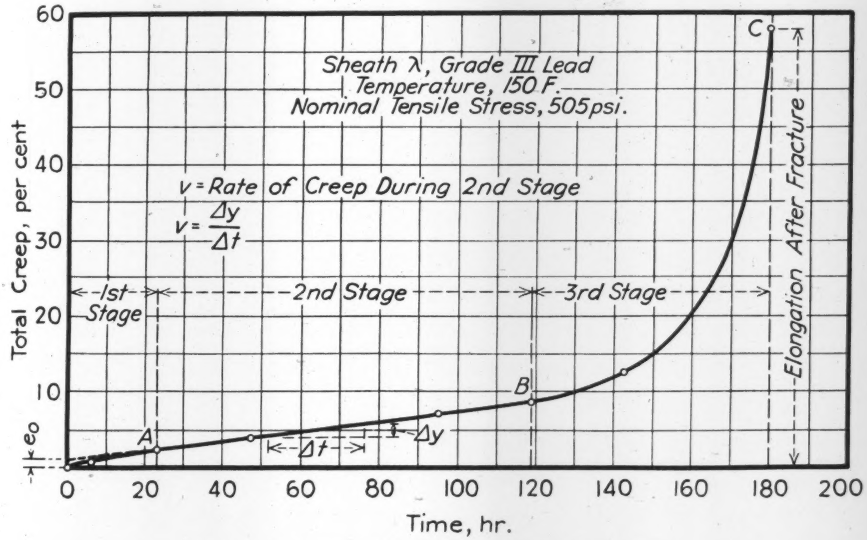


FIG. 5.—Typical Creep-Time Diagram to Fracture.
The material is A.S.T.M. grade III lead.

TESTS FOR DAMAGE BY ELASTIC DEFORMATION

Considering damage by elastic deformation, the test for resistance of a material to such damage is very simple, highly reliable, and very rarely used in practice: the determination of modulus of elasticity of the material—its stiffness within the range of its elastic strength. The reason why requirements for modulus of elasticity rarely appear in specifications is that most of those specifications have been developed in connection with steel structural and machine parts and the modulus of elasticity of steel of all grades is practically the same. However, as other metals and non-metals are brought into our specifications we have to consider their modulus of elasticity. Really we should speak not of their modulus, but of their moduli, for the modulus of elasticity in *shear* (modulus of rigidity it is sometimes called) may be as important as the modulus of elasticity in tension or compression (Young's modulus).

The test for modulus of elasticity in tension or compression is very simple but requires a carefulness in testing technique and a sensitivity of strain measurement very decidedly beyond those required for the ordinary tension or compression test. Determination of modulus of elasticity in tension or compression requires strain measurement along at least two, and preferably three, gage lines parallel to the axis of the specimen. These two or three strain measurements may be averaged mechanically. Sometimes moduli of elasticity are reported from the data of tests in which a 2-in. extensometer with a sensitivity of 0.0002 in. has been used. In my opinion such determinations are not reliable, at least not for metals, especially if the extensometer is attached along only one gage line on the specimen. The criticism of lack of sensitivity does not apply to more sensitive extensometers, such as the Tuckerman, the Martens or the Huggenberger.

Moduli of elasticity in shear are even more readily determined than moduli in tension or compression. For a discussion of their determination I refer you to the 1938 Marburg lecture by the late Doctor Sauveur.[4]

We have begun to be reasonably careful that our testing machines are calibrated and kept accurate, but we rarely think of calibrating extensometers. In determination of yield strength this is not so serious, as relative strain measurements are fairly reliable, but in determining moduli of elasticity calibration of extensometer *is* important. The A.S.T.M. as yet has no standard method for such calibration, but the Bureau of Standards and a few laboratories have calibration apparatus for strainometers based on micrometer screws, standard gage blocks, or interferometer measurements as primary standards.

The reliability of a modulus of elasticity determination as an index of resistance of a material to elastic deformation is very high. Elastic deformation of material is a statistical phenomenon, and, within the elastic strength, localized irregularities of stress distribution do not affect the distortion of a structural or machine part appreciably. For predicting elastic deformation we can use the mathematical theory of elasticity with a very high degree of confidence because the property we wish to measure is the statistical behavior of a structural or machine part as a whole.

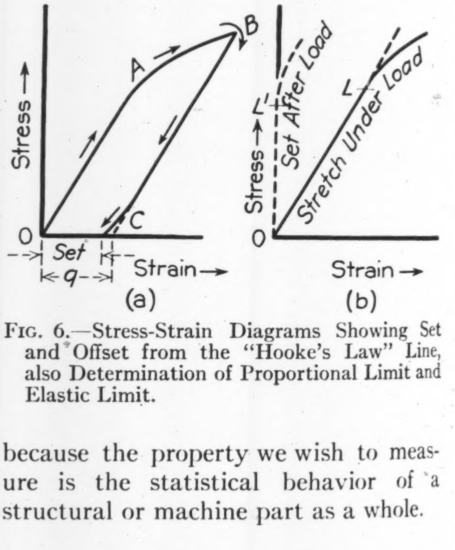


FIG. 6.—Stress-Strain Diagrams Showing Set and Offset from the "Hooke's Law" Line, also Determination of Proportional Limit and Elastic Limit.

TESTS FOR DAMAGE BY INELASTIC ACTION

Now, with considerable trepidation, I will discuss our tests for determining resistance to structural damage by failure of elastic strength of materials. First let me read our A.S.T.M. definitions of elastic and proportional limits:

> *Elastic Limit.*—The greatest stress which a material is capable of developing without a permanent deformation remaining upon complete release of the stress.

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[4] Albert Sauveur, "The Torsion Test," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 3 (1938).

Proportional Limit.—The greatest stress which a material is capable of developing without a deviation from the law of proportionality of stress to strain (Hooke's law).

We commonly regard these two limits as identical. That is we assume that at that stress where Hooke's law fails permanent set begins. This is equivalent to assuming that in Fig. 6 (*a*) *BC* is coincident with or parallel to *OA* for any point on a stress-strain diagram. There is no logical reason why this should be true, and as a matter of fact for most materials of construction it is only approximately true, as shown by the solid line in Fig. 6(*a*). For rubber this parallelism is not even approximately true. However for most materials of construction this assumption can be made without serious error.

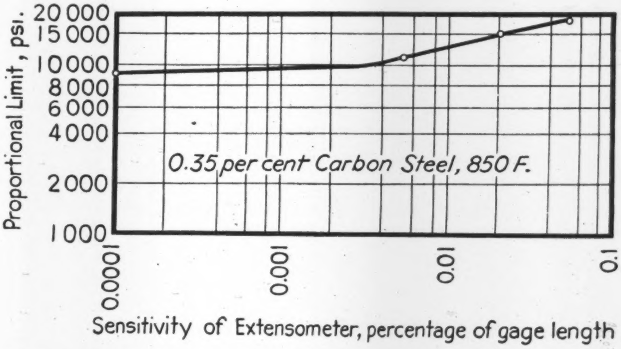

FIG. 7.—Dependence of Value of Limit of Proportionality on Sensitivity of Strain Measuring Apparatus.

From data reported by J. B. Romer.

Let us look at our definitions again. They would demand that any determination of elastic limit or proportional limit be made with apparatus of infinite sensitivity. The actual determination with any instruments now available or imaginable would be the point of first permanent set or of deviation from Hooke's law not greater than the limiting sensitivity of the apparatus used, and let me remind you that the apparatus will consist of a testing machine, some kind of strain measuring apparatus, a piece of cross-section paper, a pencil, a draftsman's triangle and a curved ruler, each of which has a limiting sensitivity. If in place of the cross-section paper and the drafting tools there is the stress-strain line drawn by an autographic attachment to the testing machine then the autographic apparatus has a limiting sensitivity.

Figure 6(*b*) shows a stress-strain diagram in which both strain under stress and set after release of stress have been plotted. Both lines are curves which, considered from the upper end, increase in radius of curvature as stress decreases and merge with what seem to be straight lines within the net sensitivity of the apparatus used. Then just above *L* we can measure a very slight deviation from Hooke's law. We then virtually extrapolate to determine the tangency point of the stress-strain line and the straight line. Really all we can say is that the proportional limit is somewhere between *L* and *O*. There is a natural feeling that it is safer to extrapolate from a small quantity toward zero than it is to extrapolate from a finite quantity toward infinity, but really one process is just as susceptible to error as the other. This is illustrated by Fig. 7 which shows a logarithmic diagram plotted by J. B. Romer of the Babcock & Wilcox Laboratories which shows the diminution of the "absolute" proportional limit as the minimum detectable strain reading approaches zero. On a logarithmic scale detectable indication of extensometer for any strain above zero by any amount however small would be plotted at an infinite distance to the left, and the possibility of the curve to the left of the diagram turning either upward or downward is evident.

All this tedious discussion is to emphasize the point that the search for an "absolute" elastic or proportional limit seems quite hopeless, and if we report a value for such a limit from data of tests with instruments of finite sensitivity we are merely determining an arbitrary limit for which the deviation from elastic action is not greater than a small but unknown amount. The "true" elastic limit is apparently undeterminable, and, could it be determined, would probably be of slight significance.

In view of the empirical nature of the elastic and proportional limits as determined by laboratory tests, the A.S.T.M. Committee on Methods of Testing has recommended that a definite limiting deviation of strain from that given for a material by Hooke's law be taken as the determining factor of resistance to structural damage by inelastic action. Such a limiting deviation is a reliable, although approximate, measure of permanent set. This limiting deviation, or "offset" will be different for different materials and for different uses of the same material. The use of this "offset" (q) to determine elastic strength is shown in Fig. 6 (a). The name "yield strength" was recommended for this value, and the "yield point" of some of the steels was recognized as a special case of yield strength.

The numerical value of the "offset" which will serve as the threshold value for structural damage must be decided by the different committees for different materials; it cannot be decided by the Committee on Methods of Testing. To illustrate this point, in one of the many debates on elastic strength which have enlivened A.S.T.M. meetings for the past 30 years it was brought out that the U. S. Navy in testing metal to serve as parts of the measuring apparatus of gun sights would set the value of "offset" at 0.05 per cent strain, or even lower. The users of structural aluminum, on the other hand have set the limit at 0.2 per cent.

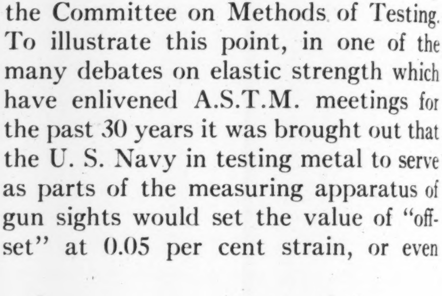

FIG. 8.—Stress-Strain Diagram Showing Upper and Lower Yield Point and Stress-Strain Diagram for Material with No Yield Point.

A word or two about our old friend the yield *point*. This is defined in the A.S.T.M. Standards thus:

> *Yield Point*.—The stress in a material at which there occurs a marked increase in strain without an increase in stress.

Figure 8 (a) shows a typical stress-strain diagram for a material which has a yield point. If the yield point is determined by the "drop of the beam" its value is Y_U; using an "offset" to determine yield strength the value Y_L would be found, a somewhat lower value. Abroad these two values are spoken of as the "upper" and "lower" yield points, respectively. As is noted in this year's report of the section on effect of speed of testing,[5] the upper yield point seems to be more affected by speed of testing than does the lower. With a testing machine with self-indicating weighing mechanism both upper and lower yield points can readily be determined; with a beam balance machine this is difficult although not impossible. The ease with which value of yield point can be affected by means of manipulation of the beam-balance testing machine is a matter of common knowledge. Many of us remember the experience related at an A.S.T.M. regional meeting by a navy inspector, who was asked by an untactful operator of a testing machine, "How do you like your yield point, high or low?"

Many testing laboratories receive requests—sometimes demands—for the determination of the yield point of a metal which has no yield point. Only a relatively few metals have a yield point; most metals have stresss-strain diagrams of the type shown in Fig. 8 (*b*). The demand that a value shall be given for a non-existent property is another reminder that our whole art of testing materials has developed around the use of structural steel as a building material. Structural steel has a yield point, but high-strength steel, cold-drawn steel, and stainless steels, in general, do not. As for the non-ferrous metals, possibly one or two of them have a yield point, but it is not so clearly marked as that for structural steel, and as for the non-metals I do not know of any which has a yield point.

It is to be hoped that testing laboratories will develop the practice of refusing to report a yield point for any metal which does not show a clearly marked drop of the beam or a definite drop, or horizontal line in its stress-strain diagram. For such metals I suggest that yield strengths for 0.05, 0.1 or 0.2 per cent "offset" (perhaps all three) be reported.

I believe that we must give up the idea of a definite elastic limit which indicates the precise beginning of inelastic action and consequent structural damage. However, I believe that by the estimation of the amount of inelastic deformation which will cause appreciable structural damage in any material and by the use of the "offset" method for determining yield strength we can obtain test data which will furnish a reliable basis for design against this particular type of structural damage.

TESTS FOR RESISTANCE TO CREEP

So far the only tests for resistance to creep which seem at all reliable are those involving direct measurement of creep over a time of at least 1000 hr. Loading mechanisms for creep tests are very simple; usually dead weights or single lever devices are used. However the strain-measuring apparatus must be very sensitive and the temperature control very close. Creep testing is distinctly in the research stage, and the acceptance test stage is not yet in sight.

Two criteria for resistance to creep have been suggested: creep rate and total creep after a given time. As shown in Fig. 5, a creep test to fracture may be divided into three stages. During the second stage the rate of creep is approximately constant, and it is this rate which is chosen as an inverse index of resistance to creep. The total creep is determined directly from a creep-time diagram.

During the first stage the amount of creep seems to depend largely on the process of evening up stress in the material and in straightening out kinks and bends. This would make it seem probable that creep rate would serve well as an inverse index of the creep resistance of the material itself, while total creep, using, if possible, full-size specimens of sheathing, pipe, bolts, etc., would serve as an inverse index of the creep resistance of finished parts.

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[5] Report of Committee E-1 on Methods of Testing, Section on Effect of Speed of Testing, see p. 520.

Short-time creep tests have proven unreliable as a basis for predicting resistance to long-time creep. It seems to me that this is because in a short-time test the first stage of creep is not passed, in which much of the distortion is due to strain adjustments in the specimen or the part. In the Talbot Laboratory at the University of Illinois a piece of calcium-lead alloy sheath under steady internal pressure showed more creep for the first 50 hr. than did a similar piece of sheath made of ordinary commercial lead. However the creep *rate* after about 2000 hr. was much less for the calcium-lead alloy sheath than for the one made of ordinary commercial lead.

No evidence of any definite "creep limit," below which no creep occurs, has been found. The situation seems somewhat similar to that for elastic strength. An estimate of the amount of creep which will cause appreciable structural damage must be made, and then from tests the combination of stress and temperature which will cause creep below this value may be determined.

Much work remains to be done in the study of creep before standards for the creep resistance of materials can be written. This is especially true for non-metals. Creep tests of concrete are on record. It has been noted that wood shows some signs of creep. The program of the Society's Committee on Plastics includes discussion of creep. Here is another wide-open field for investigation.

Tests for fracture after creep will be considered in connection with other fracture tests.

TESTS FOR RESISTANCE TO FRACTURE UNDER STATIC LOAD

The test to fracture is the oldest, the simplest, and the most definite in its results of all our mechanical tests. Tests for elastic strength and for creep are judged by empirical indices of structural damage; there is no doubt when fracture occurs. However, the significance of fracture tests is not altogether a simple matter to determine. For brittle materials, for textiles and rope, and for such parts as bolts, eyebars and tie rods, fracture tests of material have a direct significance. For ductile metals, fracture tests give a crude basis for estimating probable elastic strength and strength under repeated loading.

In connection with fracture tests, elongation before fracture and reduction of area at fracture are usually determined for ductile materials. These indices of ductility are, in my opinion, significant of the ability of the material to withstand a few severe overloads without shattering failure. Taken in connection with the tensile strength they are significant of the *energy* which can be absorbed without fracture under a single load slowly applied or under a not too rapid "impact."

For brittle materials, flexure tests are simpler to carry out than are tension tests. Less machining of specimens is necessary, and it seems easier to approach the theoretical stress-distribution than is the case for a tension specimen. It is no easy task to get a tension specimen effectively centered and gripped. It is especially difficult in the case of specimens of brittle material. However flexure tests do not yield the same stress values for fracture as do tension tests. Some action similar to that described in telling about the tests of three steel bars in flexure is effective in flexure tests to fracture. This means standard size and shape for specimens so that comparative results may be obtained.

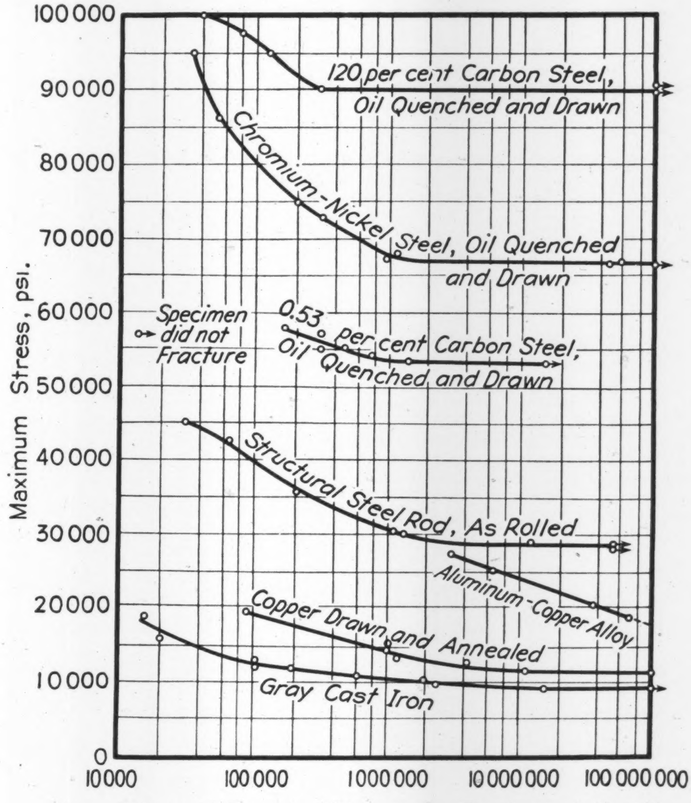

FIG. 9.—Typical *S-N* (Stress-Cycle) Diagrams for Determining Endurance Limit (Fatigue Strength) of Metals Under Repeated Stress.

For determining the tensile strength of brittle materials I call attention to the test discussed in last year's Marburg lecture,—the torsion test,[4] especially a torsion test using thin-walled hollow specimens. For brittle materials, tensile strength is nearly always, if not always, less than the shearing strength, and in a torsion specimen the tensile stress along a 45-deg. diagonal is equal in magnitude to the shearing stress on a transverse or a longitudinal section. Torsion specimens, even hollow ones, are no more expensive to machine than thread-ended tension specimens, and a number of tests of the hollow torsion specimens and tension specimens of cast iron of various grades have given results for tensile strength which agree closely. In this connection it is my opinion that for brittle materials a compression test resulting in a diagonal fracture gives the best index of shearing strength. In such a specimen the shearing stress is approximately one-half the compressive stress.

Tests for Resistance to Fracture Under Repeated Stress

Tests of resistance to fracture under repeated stress are also in the research stage. Tests of specimens carefully machined and polished give what seems to be a reliable index of the maximum possible resistance of a *metal* to repeated stress, but the resistance of a machine or structural part to repeated stress is markedly affected by shape of part, "stress raisers" such as notches, holes, and screw threads, surface condition, internal cracks, grain structure, size of piece, and stress history. Probably other factors, especially corrosion, might be listed, but let these suffice for this paper. For tests of elastic strength and fracture under static load, these factors usually play a minor part, but under repeated stress they become major factors, and our knowledge of their quantitative effects is far too meager to make it feasible to do much specification writing at present. Here the results of non-homogeneity of our materials are most evident. A minute defect may serve as a nucleus to *start* a spreading crack, and once such a crack is well started the initial resistance to repeated stress may be diminished by as much as 50 per cent.

I shall not enter into any description of fatigue testing machines. To determine the endurance limit—the stress below which fracture will not occur after an indefinitely large number of repetitions of stress (or sometimes the stress below which fracture will not occur after a given number of repetitions)—it is necessary to test a number of specimens, usually six or more, at various stresses, then to plot a diagram in which stress is plotted as ordinates and numbers of cycles of stress required for fracture as abscissas (abscissas are usually plotted to a logarithmic scale). Figure 9 shows typical diagrams, called $S - N$ or stress-cycle diagrams. The stress at which the diagram becomes horizontal is the endurance limit.

As the fatigue of metals has been my principal line of study for a good many years I find some difficulty in resisting the temptation to write a dozen pages discussing the effect of those factors which are minor in static testing and major in repeated stress testing. I will confine myself to two; size effect and stress history.

Large fatigue specimens seem to develop lower endurance limits than smaller specimens of the same material. Some metals show this size effect to a marked degree, others scarcely at all. Figure 10 is a diagram of two specimens of different size under flexure with the same stress in the extreme fibers of each specimen. Evidently the stress gradient across specimen *B* is steeper than the gradient across specimen *A*. Now recall the flexure test of the three steel bars which was described at the beginning of the lecture. A sharp stress gradient means that the most stressed outer fibers have lower stressed fibers near them, and that only a little ductility is necessary for them to get some stress relief. In a specimen with a gentle stress gradient the extreme fibers have to send farther for the same amount of stress relief. Now the stress gradient

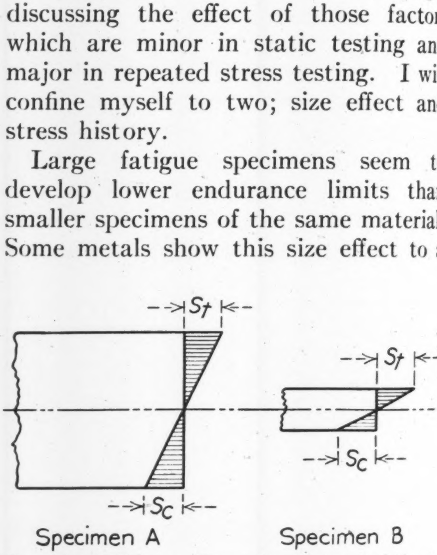

FIG. 10.—Different Stress-Gradients for Specimens of Different Size with Same Maximum Stress.

will, in general, be steeper for a small specimen than for a large one. Some day someone will test this idea out by studying size effect on tension-compression specimens under repeated stress, or, perhaps, by studying hollow specimens of different sizes in repeated flexure or in torsion. Possibly grain size has something to do with size effect, but here we shall have to wait until our metallurgist friends tell us more about what kind of grain size is the one which affects mechanical strength most.

Ductility as determined by static tension tests seems to have little effect on endurance limit; even cast iron has ductility enough to exhibit considerable stress readjustment before fatigue fracture.

The effect of stress history on fatigue strength seems to me to depend largely on that "Dr. Jekyll and Mr. Hyde" effect of cold work, which I discussed previously. Cold work strengthens and also reduces the capacity for further strengthening without cracking. A few cycles of a very high stress, stress almost up to the static ultimate strength of the metal, may increase its initial endurance limit, while a large number of such stresses may reduce it. Many thousands or millions of cycles of stress below the endurance limit increase the endurance limit. Quite a number of cycles of overstress followed by many cycles of understress may shove the endurance limit either up or down, depending—well, depending on various things. See the work of French,[6] or Brophy[7] and of Kommers[8] for further details.

The present trend in fatigue testing is toward more testing of full-size parts and a recognition of the tremendously complex situation which arises when repeated stress is applied to a piece of metal which is not homogeneous, which has external and perhaps internal "stress raisers," and which has been subjected to an imperfectly known history of overstressing and understressing.

One thing can be rather definitely said. Do not put any confidence in short-time fatigue tests—not even on the two or three I have written hopefully about. Perhaps there may be a reliable short-time fatigue test, but it has not been discovered yet, at least I have not heard of any such.

TESTS FOR RESISTANCE TO FRACTURE UNDER CREEP

Fracture may occur after creep under a steady load, and when it does so it appears as a spreading crack, spreading more slowly than does a fatigue crack. Here, in an even greater degree than is the case for fatigue, testing is in the research stage. Long-time tests seem the only reliable tests, and the time required is more than it is for fatigue. Resistance to fatigue fracture is dependent on the number of cycles of stress rather than the frequency, but resistance to fracture under creep seems dependent on time. You can "speed up" your fatigue testing machine, but you cannot speed up time. The results of a few creep tests to fracture indicate that either of two relations *may* be reliable:

$$S = S' - k \log t \quad \text{or} \quad S = S'/t^q$$

where

S = the tensile strength for any time t,

S' = the tensile strength for 1 hr., and

q and k = experimentally determined constants.

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[6] Herbert J. French, "Fatigue and the Hardening of Steels," *Transactions*, Am. Soc. Steel Treating, Vol. XXI, N. 10, October, 1933, p. 899.

[7] G. R. Brophy and E. R. Parker, "Damping Capacity—Its Variation and Relation to Other Physical Properties," *Transactions*, Am. Soc. Metals, Vol. XXIV, No. 4, December, 1936, p. 919.

[8] J. B. Kommers, "The Effect of Overstressing and Understressing in Fatigue," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 249 (1938).

Fatigue tests under elevated temperatures bring in both the effect of repeated stress and the effect of creep. As the temperature increases, the importance of the repeated stress effect diminishes and that of creep increases until for structural steel at about 1000 F. repeated stress ceases to be the governing factor and creep takes its place.

As previously acknowledged I have spoken of only four kinds of structural damage and of a few tests for resistance to them. I make my apologies to the students of corrosion-fatigue, impact, wear, and any others whom I have neglected. Again I make my apologies to the students of non-metals and urge especially that studies of structural damage be pushed in those fields, especially in the field of plastics.

The days of Galileo and his simple assumptions of absolute rigidity, uniform stress, and fracture as the only criterion of structural damage seem delightfully simple, and we sometimes envy him his ability to develop a satisfactory analysis for the needs of his day without having to worry about elastic strength, fatigue of metals, creep, wear, or corrosion. However, we have one consolation: there is no present indication that the knowledge of materials will become so complete that we will lose our jobs for want of work to do, nor that the A.S.T.M. will pass out of existence for the same reason.

A WORK-BRITTLENESS TEST FOR STEEL

By H. W. Graham[1] and H. K. Work[1]

Synopsis

Various tests may be used to measure the effect of cold work on the hardness and brittleness of steel, but most of them are slow and laborious to use. A simple test is described in this paper for measuring the changes in these properties, particularly the embrittlement on cold working. It consists essentially of drawing a tapered specimen through a die, notching it at points representing various increments of cold work, and breaking it in an Izod impact machine. The resultant work-embrittlement curve is characteristic of a given heat of steel. Experience over a period of years has shown that the test furnishes useful information as to the probable behavior of the steel during fabrication and service.

The work-brittleness test described in this paper was developed in the course of a broad study started several years ago and designed to explain unusual, and at that time "inexplicable," steel failures. The test has been extremely valuable in showing the reason for such failures, but it has done more than that: it has led to a better understanding of variations from steel to steel encountered in fabrication and service, which are not explained by ordinary chemical analysis nor predicted by simple physical tests. From this work there has been developed the concept of sensitivity which is considered an important characteristic of a steel. In its simple form, sensitivity may be described as the response of the metal to cold work. In its broader aspects, however, it is considered indicative of the behavior of steel in many of the common processing and fabricating operations.

The development of the work-brittleness test has been affected to a large degree by the circumstances surrounding the type of steel failure already mentioned. Many of these failures involved material that had been cold worked, and generally the failure occurred as a result of impact. Consequently, it was more or less natural that the test developed in these investigations should involve the impact testing of cold-worked material.

Effect of Cold Work on Physical Properties of Steel:

It is well known that cold work changes the physical properties of steel, particularly its hardness and brittleness. A piece of steel which has been cold worked by any mechanical means is found to be harder than in its original state where hardness is measured by the conventional Brinell or Rockwell test, and, speaking generally, more brittle, where brittleness is measured by the conventional Izod or Charpy test. The term "cold work" as used in this paper signifies deformation beyond the proportional limit at temperatures below that of recrystallization for the particular steel in question.

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[1] General Metallurgist, and Manager of Research and Development, respectively, Jones & Laughlin Steel Corp., American Iron and Steel Works, Pittsburgh, Pa.

The embrittling effect of cold work on steel has been the subject of numerous investigators, here and abroad, among whom Kuhle,[2] Bolsover,[3] and Epstein[4] may be specially mentioned as having contributed careful study to the problem. These and other investigators, however, have employed conventional forms of impact tests to evaluate the property of brittleness. The standard Izod or Charpy is quite convenient for an occasional test, but, in a study requiring a large number of impact strength determinations on steels cold worked in progressively increasing amounts, the preparation of individual specimens becomes a very tedious and expensive job. Graham[5] discussed the property of strain-sensitivity of steel and referred briefly to a special form of test developed to determine rapidly the effect of progressively increasing amounts of cold work on the brittleness of a specimen of steel. Case[6] also has referred to the same test. It is the purpose of this paper to describe this test rather fully, giving briefly the history of its development, its range of measurement, and some applications—as its use over a period of about ten years in the steel company, where it was developed, has proved its value for a number of applications.

TABLE I.—EFFECT OF COLD WORK ON PROPERTIES OF TWO STEELS.

Mark	Chemical Analysis, per cent				Condition	Static Properties				Dynamic Property, (Izod), ft-lb.
	Carbon	Manganese	Phosphorus	Sulfur		Tensile Strength, psi	Yield Point, psi	Elongation in 2 in., per cent	Reduction of Area, per cent	
A..........	0.22	0.35	0.016	0.031	Unstressed	62 260	42 040	36.5	65.6	86
					Cold worked 2.2 per cent	64 750	49 250	36.0	64.1	8
B..........	0.20	0.34	0.015	0.035	Unstressed	62 200	40 440	37.5	65.6	69
					Cold worked 2.2 per cent	63 540	48 520	34.5	65.5	67

Sensitivity of Steel:

Graham[5] pointed out the observed fact that two steels considered to be of identical chemical composition and possessing substantially identical static physical properties might exhibit widely different reactions to cold work, as measured by change in impact strength shown in Table I. This intensity or degree of reaction to cold work of a particular steel was denominated by him "strain-sensitivity," sometimes called "work-sensitivity" or merely "sensitivity." A steel greatly embrittled by the application of cold work is considered a sensitive steel; one only slightly embrittled by the same amount of cold work is considered insensitive. To measure the sensitivity characteristics of a given steel, the simplest method is perhaps to determine a series of Izod values of the steel cold worked in progressively increasing amounts, and then plot these Izod values numerically or as percentages of the unstressed value against the degree of cold work expressed in per cent. Such curves as are given in Fig. 1 show graphically the rate and degree of embrittlement by cold work, but are tedious to determine if an individual test specimen is made up, cold worked, and broken for each point.

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[2] A. Kuhle, "The Effect of Aging and of Blue Brittleness on the Toughness of Low Carbon Steel," *Mitteilungen aus dem Forschungs*, Instit der Vereinigte Stahlwerke, Aktiengesellschaft, Dortmund, Band 1, Lieferung 4 (1929).

[3] G. R. Bolsover, "Brittleness in Mild Steel," *Journal*, Iron and Steel Inst. (British), Vol. 119, p. 473 (1929).

[4] Samuel Epstein, "Embrittlement of Hot-Galvanized Structural Steel," *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part II, p. 293 (1932).

[5] H. W. Graham, "A Modern Conception of Steel Quality," *Yearbook*, Am. Iron and Steel Inst., Vol. 22, p. 59 (1932).

[6] S. L. Case, "Work Sensitivity: Embrittlement by Cold Work," *Metal Progress*, Vol. 32, November, 1937, p. 669.

Development of Work-Brittleness Test:

The first series of test specimens made for the purpose of determining the sensitivity characteristics of steels were prepared individually. A number of standard 0.505-in. tension test specimens were machined from the steel to be tested and pulled in a tension testing machine until the elongation between 2-in. gage marks was 2 per cent, 4 per cent, etc., to 10 per cent, respectively. Then standard 0.450-in. Izod test specimens were machined from these cold-worked specimens, with the notch located midway between the gage marks. This method naturally consumed considerable time.

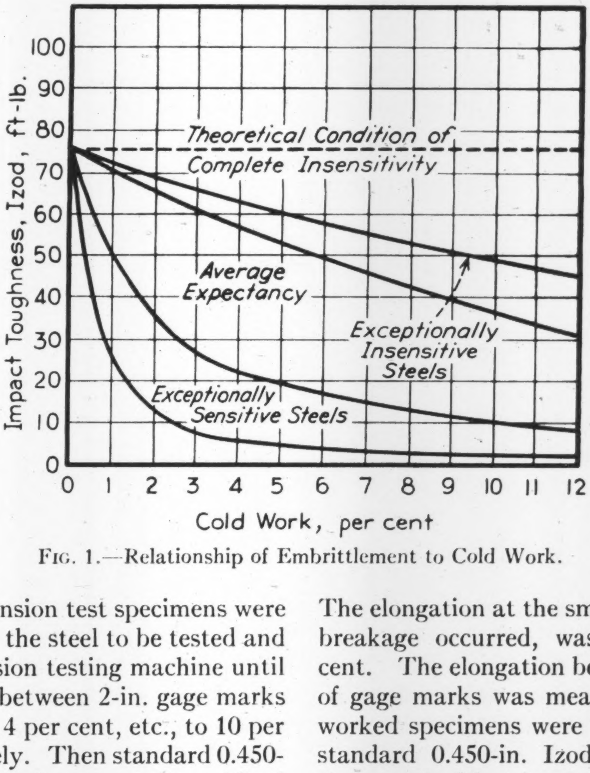

Fig. 1.—Relationship of Embrittlement to Cold Work.

It was suggested that the work of preparation of test specimens could be reduced by machining one long tapered tension test specimen, pulling it in a tension testing machine to cold work it in progressively increasing amounts from the larger to the smaller end, and then cutting Izod specimens from the cold-worked bar at various points. Consequently several round specimens 12 in. between grips were prepared, 0.750 in. in diameter at the large end and having tapers of $\frac{1}{16}$, $\frac{1}{8}$, $\frac{3}{16}$ and $\frac{1}{4}$ in., respectively, to the smaller end. These were gage-marked every inch and then pulled to destruction in a tension testing machine. The elongation at the smaller end, where breakage occurred, was about 35 per cent. The elongation between each pair of gage marks was measured, the cold-worked specimens were turned down to standard 0.450-in. Izod diameter, and then notched between each pair of gage marks. Each notch corresponded to the cold work as measured by the elongation between the gage marks on either side. This method of preparing tests was an improvement over the previous system, but was also found to be accompanied by a serious drawback. Regardless of the taper used and the relative dimensions of the test specimen, the relative degrees of elongation between successive gage marks were found to vary considerably from one steel to another, so that cold work could not be predicted, but had to be measured individually by determining elongation for every test made.

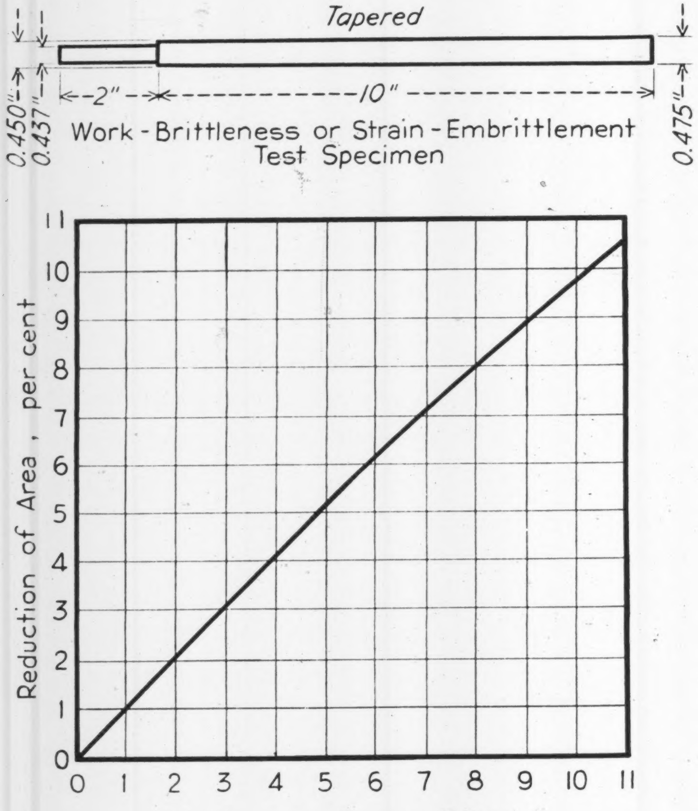

FIG. 2.—Work-Brittleness Test Specimen.

Thus far, only the effect of cold work on the impact value of the steel has been considered. However, it is obvious that the effect of cold work on hardness could be similarly measured. As a matter of fact it has been generally customary to determine the hardness as well as the brittleness. After considerable experience, however, it was decided that the impact value was more useful in discriminating between two steels than the hardness.

Standard Work-Brittleness Test:

The method finally adopted as standard involved cold working a tapered round specimen by drawing it through a die and then notching at convenient intervals. This method proved very satisfactory and has been used for routine sensitivity testing. The form of test specimen and the progressive amounts of cold work imparted to it by cold drawing are shown in Fig. 2. The degree of cold work at any point in the specimen is measured by the reduction in diameter, and is therefore a function only of the dimensions of the specimen and not the nature of the steel. The specimen is prepared by turning from the steel to be tested a round blank 10 in. long which has an additional tongue for gripping in cold drawing. The diameter of the blank tapers uniformly from 0.475 in. at the far end to 0.450 in. at the tongue end. It is machined to a good finish and then drawn through a 0.450-in. diameter die, which cold works the specimen in amounts increasing gradually from zero to a maximum of about 10.6 per cent (measured as reduction of area) at the originally 0.475-in. diameter end. In drawing, it is desirable to use a lubricant, such as powdered graphite, to preserve the surface both of the piece and the die. The original 10-in. test piece is elongated by the drawing to a trifle over 11 in. long. It is then notched with the standard Izod V-notch at 1.1-in. intervals along its length. The first notch is usually located as near as practicable to the unworked end of the piece, so as to obtain a small degree of cold work for the first stressed point plotted, because of the rapid initial drop of the sensitivity curve for ordinarily sensitive steels. If the first notch is located 0.5 in. from the end, the corresponding degree of cold work is seen from the curve of Fig. 2 to be 0.5 per cent. The amount of cold work at each succeeding notch is readily determined from the location of the notch on the specimen and the curve of Fig. 2. The unstressed Izod value, the zero value of impact strength on the sensitivity curve, is usually determined from a separate standard Izod test specimen, although the work-brittleness test specimen could be machined to provide an untapered length sufficient to support one notch for this value, if desired. The specimen is then broken at each successive notch in an Izod machine and the impact values plotted against the corresponding amounts of cold work.

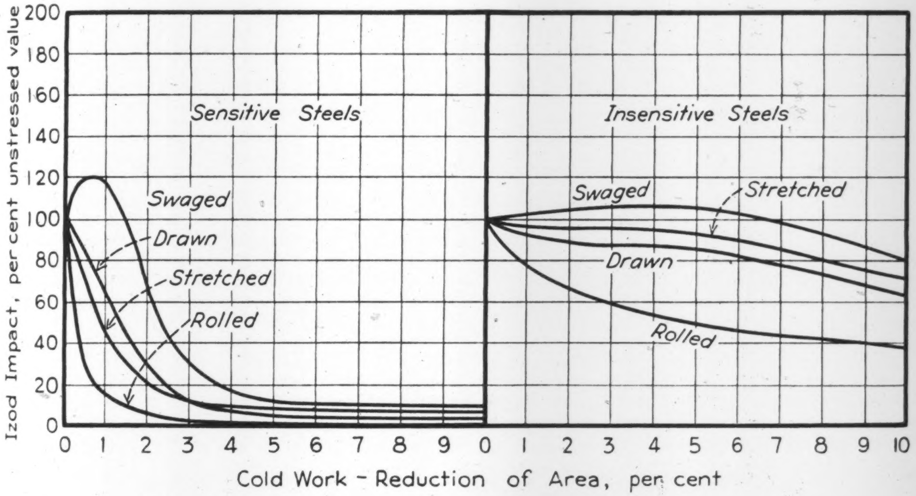

FIG. 3.—Effects of Various Types of Cold Work on Sensitivity.

This particular form of test specimen has been described in some detail because it has proved to be most convenient for measuring the sensitivity characteristics of steels—the purpose for which it was devised. However, the means of cold working the specimen, the dimensions, and the shape of the test specimen may all be varied to meet special circumstances. The effects of certain of these variations will be noted briefly.

Effect of Various Modes of Imparting Cold Work:

Cold work in controllable amounts may be imparted to steel by stressing in tension beyond the proportional limit, by twisting, drawing, rolling, swaging, and direct compressing. There is no reason for assuming that all of these modes of working produce the same effect, and in fact experiments utilizing four of these means have shown that their effects are different. The relative effects on its sensitivity characteristics of stretching in tension, rolling, swaging, and drawing as means of cold working a specimen are shown in Fig. 3 for typical sensitive and insensitive steels otherwise of comparable properties and composition. The order of effectiveness of these means of cold working in embrittling the steel is seen to be: (1) rolling, (2) drawing, (3) stretching, and (4) swaging. Regardless of which of these means of cold working is employed in preparing the work-brittleness test, however, it is seen that the test will rate the steels in their correct order of sensitivity. The effectiveness of the test is therefore independent of the means employed for applying cold work to the specimen.

The cold-drawn and stretched work-brittleness tests of Fig. 3 were prepared in the manner previously described. The swaged test was prepared similarly to the drawn test, but was swaged instead of drawn to size. The cold-rolled test was prepared by machining a tapered blank 10 in. long, 0.394 in. thick at one end, and 0.419 in. thick at the other, cold rolling it to a uniform thickness of 0.394 in., and then cutting out a test specimen 0.394 in. wide lengthwise of the blank.

No tests were made employing compression or torsion as means of applying cold work.

Effect of Specimen Dimensions:

If desired, the length, taper, or notch depth may be varied without impairing the effectiveness of the test in discriminating between steels of varying degrees of strain-sensitivity. As the test is most conveniently broken in a standard Izod machine, it has not seemed desirable to depart from the standard Izod specimen diameter or circular section, or notch spacing.

Length.—For certain purposes, a short specimen is sometimes employed, 6 in. long, tapering from 0.450 in. to 0.475 in. in diameter before drawing. This specimen is drawn, notched, and broken in the usual manner, and furnishes the same information as the 10-in. specimen, but because of the shorter length only five notches can be cut and consequently the increment of cold work between successive notches is greater than for the 10-in. specimen—about 2 per cent against about 1.2 per cent. This specimen may be prepared in a shorter time than the larger one, and is, therefore, advantageous for rapid work.

There is no reason, aside from machining difficulties, why a longer test may not be employed, either with the same taper per inch or the same total taper, if desired. The first of these possibilities has not been found to offer any considerable amount of additional information, for in the case of steel the significant effects of cold work seem to be fully revealed before the reduction in area has exceeded about 10 per cent. The second would afford a smaller increment of cold work between successive notches, which is advantageous where the slope of the sensitivity characteristic is steep, but this is the case only at low values of cold work, and is more conveniently measured by using a test blank of standard length but of smaller taper.

Taper.—As previously mentioned, a smaller taper affords a smaller increment of cold work between successive notches and is of value in measuring the sensitivity characteristics of very sensitive steels.

In Fig. 4 are plotted test results on two sensitive steels, progressively cold worked from zero to a maximum of only about 1.8 per cent reduction of area. These tests were prepared by machining a blank 6 in. long, 0.450 in. in dameter at one end, and 0.455 in. at the other. The taper was thus only 0.005 in. in 6 in., or 0.00083 in. per inch. The specimen was then drawn through the usual 0.450-in. die and notched with the standard Izod notch at 1.1-in. intervals, beginning at 0.350 in. from the originally 0.450-in. diameter end. Five notches only were cut. The impact values of both steels are seen to have dropped from their unstressed values, taken as 100 per cent, to roughly constant but much lower values at about 1 per cent cold work, corresponding roughly to the third notch on the test. It is apparent that the 10-in. specimen with 0.025-in. taper would not provide enough points for a good characteristic for these steels, as the significant effects of cold work are encompassed within the first 1 per cent of reduction of area, which in the 10-in. standard specimen would occur between the first and second notches. Incidentally, this figure illustrates the tremendous embrittling effect of very small amounts of cold work on sensitive steels.

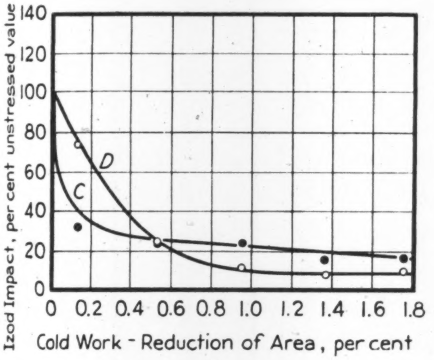

Fig. 4.—Sensitivity Characteristics of 0.08 per cent Carbon Bessemer Steels.

Notch Depth.—The standard Izod notch, 0.130 in. in depth, has been generally employed for the various forms of the work-brittleness test previously described. For very brittle steels, however, it becomes quite difficult to determine the sensitivity characteristics with any degree of precision if the standard notch depth is used, as even the unstressed Izod value is a matter of perhaps 3 or 4 ft-lb. Greater accuracy in testing very brittle steels may be obtained by notching the work-brittleness test specimen to a shallower depth. The results obtained with an extremely shallow notch—0.010 in. deep—are shown in Fig. 5. The steels tested were high-carbon spring steels of approximately 0.60 per cent carbon and 1.00 per cent manganese. The unstressed impact values, shown as 100 per cent on the curves, ranged in numerical value between 60

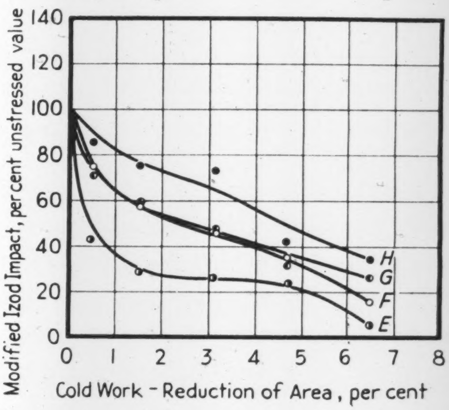

Fig. 5.—Sensitivity Characteristics of 0.60 per cent Carbon, 1.00 per cent Manganese Steels.

and 100 ft-lb. with the 0.010-in. notch, as against 2 to 3 ft-lb. with the standard depth notch. The notch depth of 0.010 in. was chosen for the tests shown in Fig. 5 merely to illustrate the extreme adaptability of the work-brittleness test, and is not recommended even for very brittle steels, since with such a very shallow notch the specimen has a tendency to break outside the notch location. A 0.030 or 0.040-in. notch largely eliminates this difficulty without reducing the actual readings to values too low to measure accurately. When a notch of other than standard Izod dimensions is employed, the impact value so obtained, of course, is no longer comparable with standard Izod values. However, the relative sensitivity characteristic of a steel is determined by the *shape* of the work-brittleness curve,—the rapidity with which the impact value falls away with increasing cold work—and as it can be plotted in terms of percentages as well as actual values, it is not necessary that the individual points on the curve be obtained in standard Izod values. All that is necessary is that the actual Izod value corresponding to the 100 per cent ordinate be known.

It will be observed from Fig. 5 that although the curves plotted have different shapes, there is no clear-cut distinction such as may be observed between the curves of sensitive and insensitive steels of lower carbon. These curves are representative of a considerable volume of data, which indicates that the sensitivity range of high-carbon steels is considerably more restricted than that of those of lower carbon contents.

Reliability:

As the work-brittleness test is in effect a form of the Izod impact test, it might be expected that its reliability would be influenced by all factors influencing the reliability of an Izod test, as well as any factors causing variations in the reaction of the steel tested to cold work. The former are well recognized and are outside the scope of this paper. The latter include heat treatment, mechanical errors in turning and drawing the specimen, and variations throughout the ingot of heat of steel of the factors responsible for the sensitivity of steel.

Heat Treatment.—To obviate the effects arising from variations in rolling temperature or cooling rate of the steel to be tested, the work-brittleness test blanks are normalized before they are machined. Normalizing after machining, without warping the specimen, seems to be impractical. The amount of cold working imparted by the machining operation appears to be inconsequential, since to secure a uniform taper and good surface it is generally necessary to finish the machining operation with several shallow cuts.

Mechanical Treatment.—Care must be exercised in turning the taper on the specimen blank, as a specimen over 10 in. long and less than ½ in. in diameter is bowed rather easily by excessive tool pressure. Non-uniform taper causes non-uniform cold working during drawing, which, of course, may introduce error into the test results. The die through which the tapered blank is drawn must be accurately aligned and the blank straight, to insure uniform peripheral distribution of cold work.

Variation of Sensitivity Characteristics Throughout a Heat.—The foregoing sources of error are easily controllable and may be eliminated with ordinary care. A third source of error lies in the possible variation throughout a billet, ingot, or heat of steel of the factors responsible for the relative sensitivity of a steel, or the manner in which it reacts to cold work. What these factors are is not known definitely, for, as has been shown in Table I, two steels of nearly identical conventional chemical composition and static physical properties may differ widely in sensitivity to cold work. Furthermore it is not the purpose of this paper to speculate concerning the possible causes of sensitivity, but to set forth the practical means by which this characteristic may be measured. To determine what variation, if any, might be expected throughout an ingot or heat of steel, a series of tests was made on a heat of killed, low-carbon, open-hearth, structural grade steel, the results of which are shown in Fig. 6. Two ingots were selected—the first and tenth. From each of these ingots the top, middle, and bottom billets were set aside and a test cut from each. All tests were normalized.

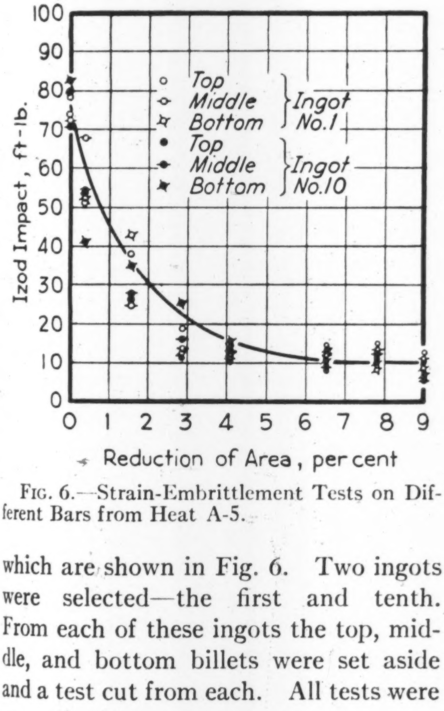

Fig. 6.—Strain-Embrittlement Tests on Different Bars from Heat A-5.

It is seen that the Izod values for the lower degrees of cold work have a tendency to scatter to a somewhat greater degree than those for the unstressed samples, but that beyond about 3 per cent cold work the scatter is no greater than at zero cold work, or no more than might be expected for a corresponding number of ordinary notched-bar impact tests. The general shape of the work-brittleness characteristic for each billet in each ingot tested is substantially the same, and indicates that the sensitivity characteristic of a given heat of steel is as uniform as other physical properties throughout the heat.

Types of Steels.—This test was devised for homogeneous steels; that is to say, those fully killed or deoxidized. It is easily seen that it is not so readily applicable to effervescing or rimmed steels, as in the preparation of the test blank by ordinary machining methods the rim portion of the steel is nearly always partially, if not wholly, removed. The test then measures the sensitivity of substantially the core portion only of the ingot. This condition is true for any type of test requiring machining for preparation of the specimen, but conventional "static" properties of rimmed steel are not in general greatly affected by the presence or absence of the rim portion. The sensitivity characteristic of a rimmed steel, however, is influenced considerably by the presence or absence of the rimmed portion; it is, in fact, probably incorrect to speak of a single "sensitivity" of a rimmed steel, as incomplete tests show an appreciable variation in this property over the cross-section of a rimmed ingot. This test, like the ordinary Izod test, is of course not applicable to steel in the form of small diameter wire, or sheet. The sensitivity of steel in these forms may be determined by a metallographic method described by Work and Case[7] in 1938.

Practical Application:

The sensitivity characteristic of a steel, which is determined by the work-brittleness test, has been found to be related to numerous other physical properties.[5, 6] Sensitive steels generally exhibit greater fatigue endurance and better machinability than less sensitive steels, while the latter generally show less tendency to age, and as already discussed, less tendency to become embrittled by cold work. As a consequence the latter are more suitable for cold forming operations. Hardenability has also been found to be related to the sensitivity characteristic of a steel, sensitive steels being in general rapid or deep hardening, while "insensitive" steels are slow or shallow hardening. Heat treatments designed to reduce brittleness and improve toughness, such as normalizing or annealing, are relatively more effective with insensitive steels, while heat treatments designed to increase brittleness, such as blue annealing, are relatively more effective in that direction with sensitive steels.

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[7] H. K. Work and S. L. Case, "A Metallographic Approach to the Study of the Sensitivity of Steel to Cold Work," Am. Soc. Metals, October Meeting (1938).

This considerable number of physical properties related to the sensitivity characteristic of a steel makes the convenient determination of this sensitivity characteristic a matter of considerable interest. For this purpose, the standard form of the test described in the preceding pages has been found to be well suited, for the test may be made at moderate expense in a reasonable time. It has been extensively used on commercial problems of the special types where it is directly applicable.

DISCUSSION

Mr. Leon S. Moisseiff.[1]—I would like to know what is the cause of the sensitivity and insensitivity, also what is the practical way that others might have in mind to avoid it? For structural purposes, an engineer would probably like to have insensitivity. How could it be specified? We certainly could not make heats and reject them if they did not show low sensitivity.

Mr. C. C. Henning.[2]—Sensitivity is affected by a good many variables in steel-making, and to some extent is controllable. While we do not know all about it that we would like to, it can be controlled within certain limits. In a general way, the austenitic fine-grained steels are insensitive. The sensitivity also varies depending on the deoxidation practice. Different steels made by different practices have different sensitivities. For instance, bessemer steel in general is more sensitive than open-hearth steel.

The Chairman (*Mr. H. H. Morgan*[3]).—I suspect that the very use of the words "sensitive" and "insensitive" implies that the condition is temperamental to a certain extent. In other words, sensitiveness and insensitiveness cannot always be counted on. Is that right?

Mr. Henning.—Yes, that is true.

Mr. N. L. Mochel.[4]—At the very close of the paper, the authors, under the subject of practical application, referred to the effect of this sensitivity and insensitivity in various tests. I should like to ask if they have considered how those materials would behave under high-temperature conditions. I suspect that these steels would behave differently.

Mr. O. E. Harder.[5]—The authors have indicated that manufacturing methods, particularly deoxidation practice, make a difference in the sensitivity of steel. Can the results of manufacturing practice be picked up by chemical analysis, for example, the nitrogen content, the oxygen content, the alumina content, etc.? I would like to know whether you could, by chemical analysis, get a line on these steels without making the sensitivity test.

Mr. Henning.—If you made as complete an analysis as that, you would come pretty close to predicting the degree of sensitivity; in other words, if you made a complete chemical analysis, including gases and your deoxidizers added, you would have some idea as to its sensitivity, although even there you would get some variation, particularly in the sensitive steel.

Mr. W. M. Patterson.[6]—The authors have developed a new test of very direct usefulness in the determination of the suitability of cold-drawn metals, such as wire or sheet, for further cold processing.

It would be interesting to know whether any work has been done in comparing the brittleness or sensitivity factor with the ability to flow as it tends to harden in further work. I am thinking particularly of cold heading of cold-drawn wire and would like to know whether the sensitivity factor found on a cold-worked material is inherent or can be influenced by heat treatment after cold drawing.

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[1] Consulting Engineer, New York City.

[2] General Metallurgist, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

[3] Manager, Rail and Fastenings Dept., Robert W. Hunt Co., Chicago, Ill.

[4] Metallurgical Engineer, Westinghouse Electric and Manufacturing Co., Philadelphia, Pa.

[5] Assistant Director, Battelle Memorial Inst., Columbus, Ohio.

[6] Engineer of Tests, Parker-Kalon Corp., New York City.

Mr. Henning.—Of course, heat treatment after cold drawing would largely eliminate the effects of the cold work.

Mr. Patterson.—It does not change the relationship between the work-hardenability and the work-brittleness factor?

Mr. Henning.—Yes; I did not go into that, but the work-hardness curves have the same trend as the brittleness curves.

Mr. Patterson.—Then a material which is shown to be sensitive in the work-brittleness test will always work-harden rapidly?

Mr. Henning.—Yes, and *vice versa.*

Mr. Haakon Styri.[7]—Is there any difference in cold-working and endurance properties between sensitive and insensitive steel?

Mr. Henning.—Our tests indicate that the fatigue endurance of sensitive steels is greater than of insensitive steels. Our results show an endurance ratio of about 52 to 54 per cent. Those are just round figures; as against 42 to 45 per cent on insensitive steels.

Mr. Morgan.—I would like to mention a matter which may or may not have a bearing on this subject.

The subject of this paper may have a bearing on steel which gets its work-hardening in service. In normal years, two and one-half million tons of steel rails are produced; at present about a million and a half tons per year are produced. Apparently, we have sensitive steel in certain heats of rail steel. Such occasional heats develop the phenomena of shatter-cracks with resultant transverse fissures in service. Such investigations as have been made have not as yet definitely determined why such heats are sensitive, but we are encouraged by the fact that the sensitive condition is being corrected, we hope, by the present controlled cooling process where the steel is held for a minimum of 14 hrs. in closed boxes through a temperature change of from 1000 F. to 300 or 400 F. We know that this treatment is taking out shatter-cracks and we hope that it will eliminate the development of transverse fissures in service. I emphasize the fact that this condition is produced only in certain heats that can properly be called sensitive heats.

Mr. Henning.—We do not make rails and therefore do not have any actual experience with them, but where the cold work is produced in service, the reaction is just the same. When we stop to think of it, all steel produced is cold worked in some manner or form such as machining, bending, etc.

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[7] Director of Research, SKF Industries, Inc., Philadelphia, Pa.

THE RELATION OF CARBON NODULE SIZE AND TENSILE PROPERTIES OF MALLEABLE CAST IRON[1]

By H. A. Schwartz,[2] H. J. Schindler[3] and J. F. Elliott[3]

Synopsis

A given white cast iron was converted into malleable irons varying widely in nodule number. It is shown that a great variation in nodule number has little effect on the tensile strength and yield strength but that a small nodule number is favorable to ductility.

It appears reasonable that in a two-phase alloy such as malleable cast iron the physical properties might well be a function of the size of particles of the discontinuous phase.

Since it is relatively simple to cause a given white cast iron on graphitization to deposit a wide variety of sizes of temper carbon nodules, it should be relatively easy to determine how important nodule size is and its effect on tensile properties.

Experimental Method:

Sixteen test coupons of the form usual for malleable cast iron[4] were divided into four groups, each group being given a different heat treatment:

Group *A* was heated to 950 C. for 1 hr., oil quenched and drawn for about a half hour at 500 C.

Group *B* was similarly heat treated except that the initial temperature was 825 C.

Groups *A*, *B* and *C* were then all given a commercial anneal.

Group *D* was packed in a 3-in. pipe in pig iron borings, heated for 26 days at 725 C., cooled and heated 22 days more at 725 C., cooled and heated 25 days at 710 C. The interruptions were made to permit micro examination of the specimen to learn the progress of graphitization.

The commercial annealing cycle consisted of heating in 5 hr. to 815 C., in 4 more hours to 925 C., maintaining this temperature 46 hr., cooling in 4 hr. to 905 C., in 22 more hours to 680 C. and then maintaining for 26 hr. a temperature within the range 680 to 715 C. In each case the metal was completely graphitized at the conclusion of the annealing period.

The specimens were then turned to 0.505 in. in diameter with $\frac{3}{4}$-in. threaded ends and the four bars in each group tested in the usual manner.

The yield strength reported is the so-called Johnson's elastic limit where the relation of strain to stress has become one and one-half times the initial relation.

Microsections were prepared near the point of fracture and the number and size distribution of the temper carbon nodules determined by the well-known method.[5]

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[1] The data of this paper form the basis of a thesis presented by H. J. Schindler and J. F. Elliott to Case School of Applied Science in 1938 in partial fulfillment of the requirements for the degree of Bachelor of Science in Metallurgical Engineering.

[2] Manager of Research, National Malleable and Steel Castings Co., Cleveland, Ohio.

[3] Case School of Applied Science, Cleveland, Ohio.

[4] Standard Specifications for Malleable Iron Castings (A 47 - 33), 1936 Book of A.S.T.M. Standards, Part I, p. 486.

Data:

It seems unnecessary to submit individual stress-strain curves or even the individual results obtained on bars of the same group since the data are closely concordant. Averaged by groups the results were as follows:

Group	Tensile Strength, psi.	Yield Strength, psi.	Elongation, per cent	Reduction of Area, per cent	Nodules per Cubic Millimeter
A........	53 940	29 000	16.5	14.2	40 686
B........	54 885	27 325	11.9	9.7	28 456
C........	53 255	30 175	21.7	19.4	135
D........	56 550	37 375	21.3	20.8	30

Discussion:

It appears that the tensile strength is practically not at all affected by the distribution of the temper carbon except in the case of group *D*. Since, in order to produce very coarse nodules, the anneal was conducted entirely below the critical point, it is barely possible, but not at all likely, that the difference is due to the heat treatment of the ferrite. A similar statement may be made with regard to the yield strength. The elongation of the relatively coarse nodule iron is definitely higher than that containing finer nodules. The reduction of area follows a very similar rule.

It is unfortunate that so large a gap exists between the nodule numbers of groups *B* and *C*. This is due to the fact that while the prequenching treatment will give very fine nodules,[6] no method was known to us for insuring that the present metal could be annealed with a nodule number of say 1000 or 2000 per cu. mm.

Conclusions:

The nodule size of the temper carbon has little effect on either the yield strength or tensile strength of malleable iron as determined on machined specimens. A decrease in nodule number from about 28,000 to about 135 per cu. mm. is accompanied by an important improvement in ductility. No sufficient theory exists with regard to the physical properties of heterogeneous mixtures to permit a rational explanation.

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[5] H. A. Schwartz, "The Metallographic Determination of the Size Distribution of Temper Carbon Nodules," *Metals and Alloys*, Vol. 5, June, 1934, p. 139.

[6] H. A. Schwartz, H. H. Johnson and C. H. Junge, "Graphitization of Prequenched White Cast Iron," *Transactions*, Am. Soc. Steel Treating, Vol. 17, p. 383 (1930).

DISCUSSION

MR. MIETH MAESER.[1]—I should like to ask whether quenching in hot salt at various temperatures has been tried.

MR. C. H. JUNGE.[2]—We have done a very little work in that connection in some experiments suggested by Axel Hultgren when he was over here from Sweden last summer. The work was done on very small specimens. We thought we found that a layer of martensite was necessary to the formation of this very fine-temper carbon.

MR. MAESER.—We have found that we can get any grain size or structure we want by controlling the temperature of the salt. I am sure from my own experience with cast iron that you will not need too small specimens; you can get a perfectly good structure on specimens as large as 1 in. in diameter.

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[1] Materials Engineer, United Shoe Machinery Corp., Beverly, Mass.

[2] Research Staff, National Malleable and Steel Castings Co., Cleveland, Ohio.

THE RESISTANCE OF HIGH-SILICON MALLEABLE IRON TO DRILLING[1]

By H. A. Schwartz,[2] R. C. Kasper[3] and N. E. Mertz[3]

Synopsis

The machinability by drilling of malleable cast iron ranging from 2.09 to 2.36 per cent carbon and from 1.39 to 2.10 per cent silicon has been determined in the Olsen Efficiency Machine. Both elements are shown to reduce the resistance to drilling.

It is not desired that these data should be interpreted as to the desirability or practicability of making metal of this composition for any particular commercial purpose. The data apply in the absence of primary graphite. This is not to say that such absence can always be relied on.

In view of recent interest in malleable irons containing what would a few years ago have been considered abnormally high silicon contents, it seemed desirable to gain laboratory knowledge of the machinability of such irons in relation to silicon and carbon content. For various reasons, the chief of which is that in the Research Laboratory of the National Malleable and Steel Castings Co. the measurement of drilling resistance has been frequently carried out, a drilling test was selected as a means of comparing the machinabilities of the several materials.

Experimental Method:

The machine and method for making drilling tests have been described elsewhere.[4] The material available for the investigation consisted of a series of commercial malleable irons having the following compositions before malleabilization:

	Carbon, per cent	Silicon, per cent		Carbon, per cent	Silicon, per cent
No. 1	2.09	1.83	No. 9	2.10	1.66
No. 2	2.31	1.39	No. 10	2.16	1.60
No. 3	2.12	1.60	No. 11	2.14	1.48
No. 4	2.33	1.58	No. 12	2.21	1.67
No. 5	2.33	1.58	No. 13	2.21	1.55
No. 6	2.03	1.68	No. 14	2.24	1.78
No. 7	2.20	2.10	No. 15	2.25	1.68
No. 8	2.20	1.60	No. 16	2.36	1.99
			No. 17	2.16	1.50

The specimens were all annealed together using a commercial cycle as follows:

5 hr. from room temperature to 815 C.
4 hr. from 815 C. to 925 C.
46 hr. at 925 C.
4 hr. from 925 C. to 905 C.
22 hr. from 905 C. to 680 C.
26 hr. within the range of 680 C. to 715 C.

Tests were made generally on four specimens of each kind. The rate of penetration of a standard $\frac{1}{2}$-in. drill pressed against the specimen by a load of 220 lb. was recorded and also the torque of a similar drill penetrating the material at the rate of 0.005 in. per revolution. Dulling of the drill was provided against by procedures described in the earlier paper by the author.[4] The results were as follows:

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[1] The data for this paper form the basis of a thesis presented by R. C. Kasper and N. E. Mertz to Case School of Applied Science in 1938 in partial fulfillment of the requirements for the degree of Bachelor of Science in Metallurgical Engineering.

[2] Manager of Research, National Malleable and Steel Castings Co., Cleveland, Ohio.

[3] Case School of Applied Science, Cleveland, Ohio.

[4] H. A. Schwartz, "Factors Affecting Machinability of Malleable Cast Iron," *Transactions*, Am. Foundrymen's Assn., Vol. XXXVIII, p. 210 (1930).

	Revolutions per 1-in. Penetration	Torque, in-lb.
No. 1	240	35.7
	240	38.8
	240	34.8
	230	38.2
No. 2	260	36.0
	260	37.6
	250	37.6
	250	37.0
No. 3	240	37.3
	240	36.7
	240	38.8
	235	36.3
No. 4	240	41.3
	280	35.4
	280	37.6
	280	38.8
No .5	270	37.6
	270	38.5
No. 6	240	36.3
	240	37.6
	240	37.0
	230	38.8
No. 7	260	37.0
	240	37.6
	240	
	240	
	240	
	240	
No. 8	220	33.3
	220	44.0
	240	33.0
	260	36.0
No. 9	240	35.7
	240	36.3
	230	41.6
	230	37.0
No. 10	260	38.2
	260	37.9
	250	33.3
	240	38.5
No. 11	260	34.8
	270	37.6
	290	39.4
	290	38.2
No. 12	290	39.4
	300	34.8
	280	38.8
	280	37.6
No. 13	270	39.4
	240	39.4
	270	35.1
	270	35.1
No. 14	250	30.2
	260	30.2
	260	35.1
	250	36.3
No. 15	270	38.8
	240	36.3
	260	35.4
	260	40.0
No. 16	260	35.1
	260	37.0
	260	37.3
	240	38.2
No. 17	240	32.6
	240	33.9
	240	30.2
	240	35.1
	240	34.2
	240	34.8
	250	35.1
	240	35.1
	230	31.4
	240	36.7
	230	37.0
	250	38.8
	220	

The multiplicity of results on material No. 17 was obtained in order to evaluate the precision of the test method.

Discussion:

By the usual statistical methods we find the standard deviation of the results on a single material, No. 17, to be 6.4 revolutions per 1-in. penetration and 2.28 in-lb. of torque. Assuming that either variable could be represented by an equation of the form

$$\text{Variable} = a + b\ \text{Si} + c\ \text{C},$$

the values of the constants a, b and c were calculated by the usual method of least squares. In this way it is determined that

$$\text{Revolutions per 1-in. penetration} = 257 - 0.49\ \text{Si} - 0.80\ \text{C}$$

and

$$\text{Torque} = 38.0 - 0.338\ \text{Si} - 0.154\ \text{C}.$$

In these equations Si and C are the silicon and carbon contents expressed in per cent.

Computing the deviations of the observed values from the calculated, we find a standard deviation from the calculated value of 18 revolutions per 1-in. penetration and of 2.31 in-lb.

It is to be noted that the agreement between torque data and the calculated value is about as close as the expected accuracy between frequently repeated runs of the test, whereas the scatter of the penetration data is about three times as great above and below the calculated value as the scatter of observations on a single material above and below the average.

It is probably a reasonable conclusion that unconsidered variables affect the penetration test by detectable amounts but not the torque test.

Conclusions:

It is concluded that both carbon and silicon improve the machinability of malleable iron as measured by the rate of penetration of a standard drill or as measured by the torque on a drill running with a predetermined advance per revolution.

Silicon is about twice as effective as carbon in reducing the torque, and carbon is almost as effective as silicon in reducing the number of revolutions required to penetrate 1 in. at standard load. The results with regard to torque are less affected by unknown variables existing between different heats than the results regarding penetration.

DISCUSSION

THE CHAIRMAN (*Mr. J. J. Shuman*[1])—It occurs to me to ask whether the analyses given here for carbon and silicon are representative of the spread of carbon and silicon which might be expected in high-silicon malleable castings, or whether they are more representative of a single type of malleable castings.

MR. C. H. JUNGE.[2]—I am not particularly familiar with the origin of this material. It originated as the result of a number of experimental heats which were made at one of our plants. We collected, over a period of some time, a series of these heats and I think we just waited until we had enough of them on hand in order to have a fairly large spread in our silicon content.

MR. J. S. VANICK.[3]—I would like to ask whether the authors, in compiling this work, have made any attempt to compare the strengths of these irons or their range of strength and the range of hardness from the surface to the core.

MR. JUNGE.—We have no data on record, so far as I know, on the strength of these particular irons as compared with their hardness and machinability. Of course the machinability which we get, or this measure of machinability, is only concerned with the material in the center of the bar. Obviously, when you ordinarily machine a malleable casting, you are more interested in the skin machinability. The results we have now have no reference to surface machinability whatever.

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[1] Inspecting Engineer, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

[2] Research Staff, National Malleable and Steel Castings Co., Cleveland, Ohio.

[3] Metallurgist, The International Nickel Co., Inc., Bayonne, N. J.

MECHANICAL PROPERTIES OF A HIGH-STRENGTH CAST IRON

BY JASPER O. DRAFFIN[1] AND W. L. COLLINS[1]

SYNOPSIS

This paper presents the results of tests on a high-strength cast iron. The tests closely parallel similar tests of a low-strength iron presented before the Society in 1937 and 1938;[2, 3] wherever feasible, comparisons between the two types of iron are made. Tests were made in (1) tension, on solid and hollow specimens; (2) compression, with specimens having length to diameter ratios of 3 and 6; (3) torsion, with solid specimens $\frac{3}{4}$ in. and 1 in. in diameter and with hollow specimens of various wall thicknesses; (4) repeated stress in completely reversed torsion with and without a hole; and (5) bending of solid rectangular and H-beams. Strain readings were taken on nearly all specimens except those tested under repeated torsion. Measurements were made to determine Poisson's ratio for the top and bottom of each beam.

Two papers have been presented before this Society, by the authors, dealing with the strength properties of low-strength (gray) iron in tension and torsion.[2, 3] The present paper presents data on the strength properties of a high-strength cast iron tested in (1) tension, (2) compression, (3) torsion, (4) repeated torsion, and (5) bending. While the results are by no means conclusive, they point to certain relationships and are presented as a fairly complete set of tests on a single heat of iron. The investigation was carried out as part of the work of the Engineering Experiment Station of the University of Illinois.

MATERIAL AND TEST SPECIMENS

The test specimens were machined from four bars or castings, each 3 in. square and having a minimum length of 63 in. The bars were cast in a vertical position, and poured from the bottom, in the Machine Laboratories of the University of Illinois. The melting was done in a cupola furnace and the charge consisted of scrap steel. Two of the alloying elements, silicon and manganese, were added in the cupola, and nickel and molybdenum were added in the ladle. The chemical composition was determined by The American Cast Iron Pipe Co. and is given below. Each value is the average of duplicate analyses, except as noted:

Silicon, per cent	1.17
Sulfur, evolved as H_2S, per cent	0.090
Sulfur, gravimetric, per cent	0.123[a]
Manganese, per cent	0.87
Phosphorus, per cent	0.06
Total carbon, per cent	3.06
Graphite, per cent	2.25
Combined carbon (by difference), per cent	0.81
Copper, per cent	0.11[b]
Chromium, per cent	0.08[b]
Nickel, per cent	1.20
Molybdenum, per cent	0.91

[a] Analysis from standard sample was 0.120 as compared with the certificate value of 0.122.

[b] Single analysis.

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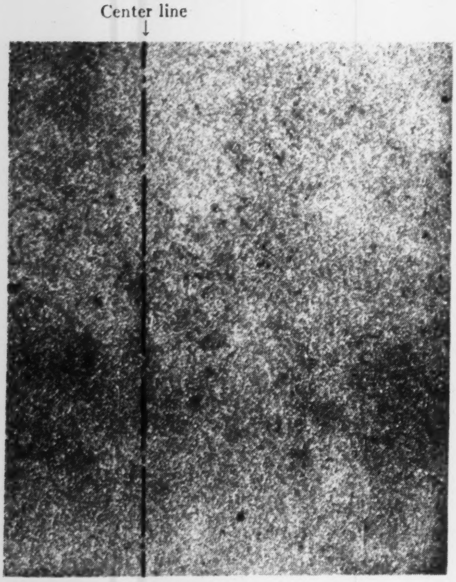
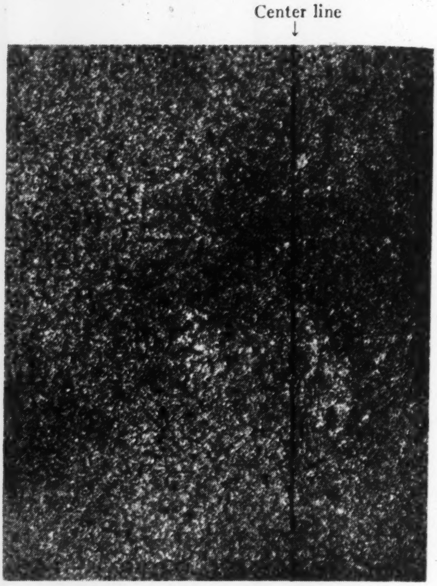
[1] Professor, and Associate, respectively, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[2] J. O. Draffin and W. L. Collins, "The Tensile Strength of Cast Iron," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 88 (1937).

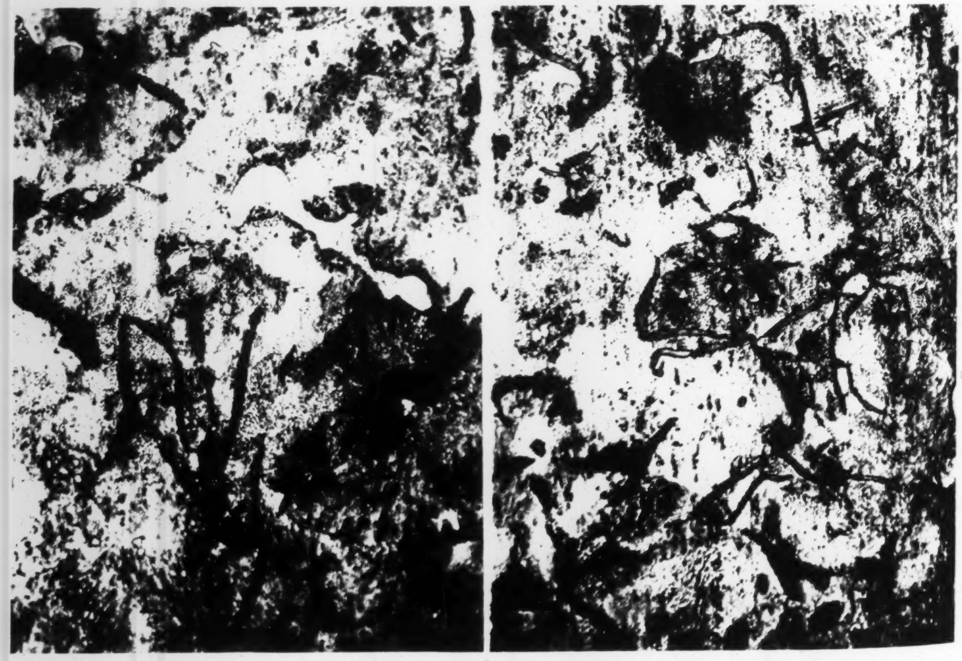
[3] J. O. Draffin and W. L. Collins, "Effect of Size and Type of Specimen on the Torsional Properties of Cast Iron," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 235 (1938).



(a) From mid-length of casting No. 4. Etched with saturated solution of ammonium persulfate. Natural size.

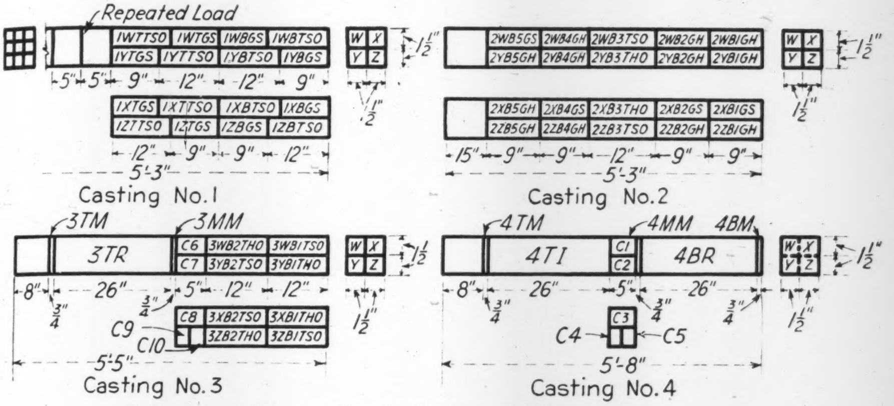


(b) From mid-length of casting No. 4. Etched with 2 parts H_2SO_4, 1 part HCl, and 3 parts H_2O. Natural size.



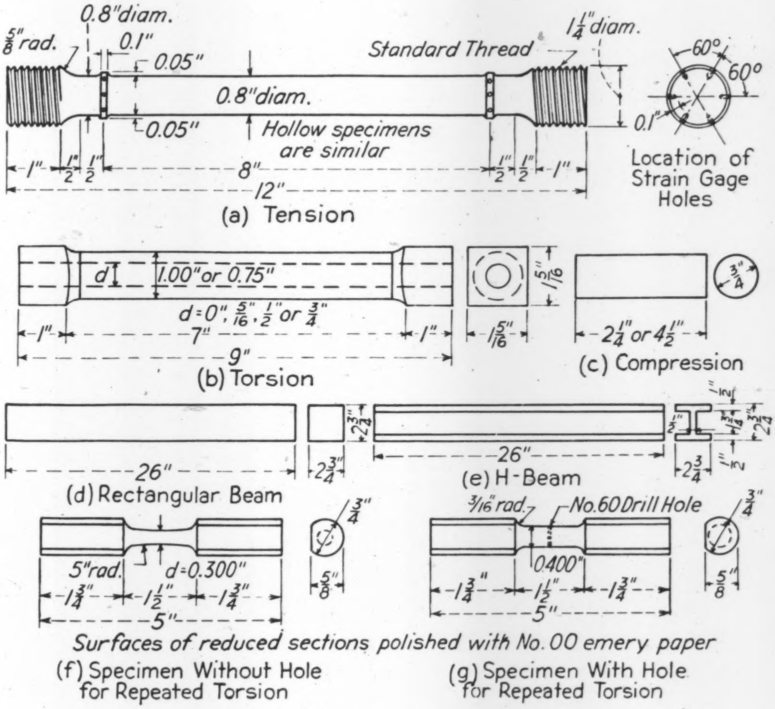
(c) From specimen 2ZB2GH. Etched with 2 per cent Nital (× 200).

FIG. 1.—Structure of High-Strength Cast Iron.


Repeated Load
1WTTSO
1WTGS
1WBGS
1WBTSO
1YTGS
1YTTSO
1YBTSO
1YBGS
5"
5"
9"
12"
12"
9"
1XTGS
1XTTSO
1XBTSO
1XBGS
1ZTTSO
1ZTGS
1ZBGS
1ZBTSO
12"
9"
9"
12"
5'-3"
W
X
Y
Z
1½"
½"
Casting No.1
2WB5GS
2WB4GH
2WB3TSO
2WB2GH
2WB1GH
2YB5GH
2YB4GH
2YB3THO
2YB2GH
2YB1GH
2XB5GH
2XB4GS
2XB3THO
2XB2GS
2XB1GS
2ZB5GH
2ZB4GH
2ZB3TSO
2ZB2GH
2ZB1GH
15"
9"
9"
12"
9"
9"
5'-3"
1½"
1½"
Casting No.2
3TM
3MM
3TR
C6
3WB2THO
3WB1TSO
C7
3YB2TSO
3YB1THO
C8
3XB2TSO
3XB1THO
3ZB2THO
3ZB1TSO
C9
C10
8"
26"
5"
12"
12"
¾"
¾"
5'-5"
1½
1½"
Casting No.3
4TM
4MM
4BM
4TI
C1
C2
4BR
C3
C4
C5
8"
26"
5"
26"
¾"
¾"
¾"
5'-8"
1½"
1½"
Casting No.4

Note: All castings cast vertically, tops at left as shown

FIG. 2. Position of Specimens in Castings.


⅝" rad.
0.8" diam.
0.1"
0.05"
0.05"
0.8" diam.
Standard Thread
1¼" diam.
Hollow specimens are similar
1"
½"
½"
8"
½"
½"
1"
12"
60°
60°
0.1"
Location of Strain Gage Holes
d
1.00" or 0.75"
d = 0", 5/16", ½" or ¾"
1"
7"
1"
9"
1 5/16"
1 5/16"
2¼" or 4½"
¾"
26"
2¾"
2¾"
26"
½"
¾"
2¾"
½"
2¾"
½"
5"rad.
d = 0.300"
1¾"
1½"
1¾"
5"
¾"
⅝"
3/16" rad.
No. 60 Drill Hole
0.400"
1¾"
1½"
1¾"
5"
¾"
⅝"

(a) Tension

(b) Torsion

(c) Compression

(d) Rectangular Beam

(e) H-Beam

Surfaces of reduced sections polished with No. 00 emery paper

(f) Specimen Without Hole for Repeated Torsion

(g) Specimen With Hole for Repeated Torsion

FIG. 3.—Details of Test Specimens.

Because of mechanical difficulties which arose at the time of pouring, the castings were not entirely sound; a number of small blowholes near the surface of the castings made some of the proposed test specimens defective and thus left a few gaps in the series as originally planned. The grain of the iron was fine, as Fig. 1 (*a*) and (*b*), taken over the cross-section at the mid-length of casting No. 4, shows. Figure 1 (*c*) was taken from one end of the ruptured specimen 2ZB2GH. The location of the various specimens in each casting is shown in Fig. 2 and the details and dimensions of the specimens are shown in Fig. 3.

TABLE I.—RESULTS OF TENSION TESTS OF HIGH-STRENGTH CAST IRON.

Specimen Number	Outside Diameter, in.	Inside Diameter, in.	Area, sq. in.	Maximum Load, lb.	Tensile Strength, psi.	Maximum Unit Strain, in. per inch[a]	Modulus of Elasticity, psi.
1WTTSO	0.801	....	0.5039	22 450	44 600	0.00480	17 400 000
1ZTTSO	0.800	....	0.5027	21 380	42 500	0.00405	18 000 000
1YTTSO	0.798	....	0.5001	21 230	42 500	0.00395	17 000 000
1XTTSO	0.798	....	0.5001	22 990	46 000	0.00515	17 100 000
1YBTSO	0.799	....	0.5014	24 040	48 000	0.00525	18 300 000
1XBTSO	0.799	....	0.5014	25 970	51 700	0.00723	19 400 000
1WBTSO	0.800	....	0.5027	24 900	49 500	0.00618	19 100 000
1ZBTSO	0.800	....	0.5027	25 840	51 400	0.00715	18 700 000
Average, upper half casting No. 1					43 900	0.00449	17 400 000
Average, lower half casting No. 1					50 200	0.00645	18 900 000
2WB3TSO	0.801	....	0.5039	22 160	44 000	0.00383	18 700 000
2ZB3TSO	0.799	....	0.5014	23 800	47 500	0.00472	20 500 000
2YB3THO	0.800	0.500	0.3063	12 300	40 200	0.00317	17 900 000
2XB3THO	0.800	0.499	0.3075	12 000	39 000	0.00303	18 200 000
Average, solid specimens casting No. 2					45 800	0.00428	19 600 000
Average, hollow specimens casting No. 2					39 600	0.00310	18 100 000
3YB2TSO	0.801	....	0.5049	24 320	48 300	0.00504	18 800 000
3XB2TSO	0.800	....	0.5027	23 900	47 500	0.00488	18 300 000
3WB1TSO	0.800	....	0.5027	26 450	52 600	0.00738	18 500 000
3ZB1TSO	0.799	....	0.5014	25 670	51 100	0.00670	20 000 000
3WB2THO	0.800	0.500	0.3063	14 600	47 600	0.00500	18 500 000
3ZB2THO	0.800	0.499	0.3075	12 600	41 000	0.00320	18 500 000
3YB1THO	0.800	0.500	0.3063	15 800	51 500	0.00635	19 200 000
3XB1THO	0.800	0.500	0.3063	15 200	49 600	0.00580	18 300 000
Average, solid specimens casting No. 3					49 900	0.00600	18 900 000
Average, hollow specimens casting No. 3					47 400	0.00509	18 600 000

[a] Average of six gage lines.

DATA FROM TESTS

Hardness Tests:

Brinell hardness tests were made on the four rectangular ends of a large number of torsion specimens. Four specimens taken from different parts of casting No. 1 gave, as an average of the four sides, a hardness number of 242 for the one from the bottom, 229 and 234 for those at the top, and 228 for the one near the middle. A somewhat similar variation was found for casting No. 2.

Two hardness traverses, using a Rockwell machine, were made across specimen 4M, one being through the center and perpendicular to two sides and the other on a parallel line connecting the centers of two quadrants, that is, centers of two adjacent test specimens. Twelve readings at intervals of $\frac{1}{4}$ in. were taken for each traverse. The readings from outside to center of castings varied from 99.4 to 97.2 R_B for the centerline traverse and from 99.6 to 97.5 R_B for the traverse through centers of adjacent specimens. These hardness readings indicate a great degree of uniformity throughout the cross-section, a conclusion also borne out by the photographs shown in Fig. 1. The differences for each traverse are much less than those found for similar traverses for low-strength iron, 87 to 81 R_B and 86 to 79 R_B, respectively.

Tension Tests:

Tension tests were made in a 50,000-lb., screw-power testing machine and longitudinal strain measurements were made on six gage lines spaced 60 deg. apart circumferentially; readings were taken at close intervals of load to failure. Holes for the points of the strain gage were drilled in collars turned on the specimens and in most cases Robertson shackles were used to eliminate accidental eccentricity in loading. While there were differences in the strains on the different gage lines of a single specimen, the differences were generally not in excess of 5 per cent above or below the average for the specimen. The results of these tests are given in Table I, and typical stress-strain curves are shown in Fig. 4. As with the low-strength iron, the location of the fracture was not influenced by the collars for the strain gage holes or by the fillets at the ends of the reduced sections. Of the 20 specimens tested, only three broke at the collars and eleven broke within the middle 6 in. of the 8-in. gage length.

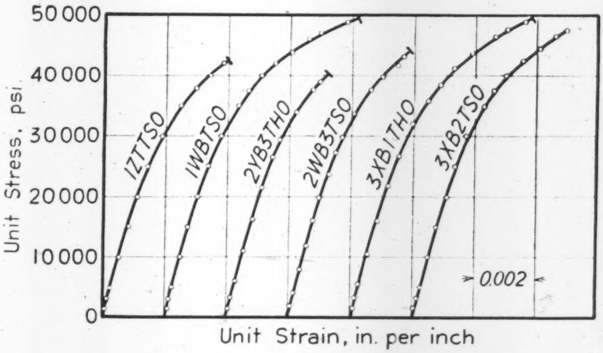


FIG. 4.—Typical Stress-Strain Curves for Tension.

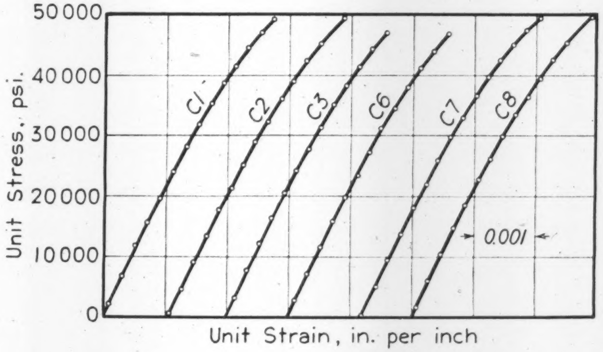


FIG. 5.—Lower Portions of Stress-Strain Curves for Compression.

It is evident that there is a variation in the strength of the iron from top to bottom of castings, as shown by the hardness tests and by the progressive increase in the strength of the specimens from top to bottom. A variation in strength is practically always accompanied by a similar variation in the maximum tensile unit strain. The

TABLE II.—RESULTS OF COMPRESSION TESTS OF HIGH-STRENGTH CAST IRON.

Specimen Number	Length, in.	Diameter, in.	Ratio, Length to Diameter (l/d)	Maximum Load, lb.	Compressive Strength, psi.	Modulus of Elasticity, psi.
4C	2.25	0.750	3.0	68 700	157 000	
5C	2.25	0.751	3.0	69 780	160 000	
9C	2.25	0.751	3.0	64 600	146 000	
10C	2.25	0.751	3.0	65 000	147 000	
1C	4.50	0.751	6.0	52 180	117 900[a]	20 500 000
2C	4.50	0.751	6.0	53 000	119 700[a]	20 500 000
3C	4.50	0.751	6.0	50 850	114 800[a]	21 000 000
6C	4.50	0.751	6.0	51 500	116 200[a]	20 500 000
7C	4.50	0.751	6.0	51 100	115 300[a]	20 700 000
8C	4.50	0.751	6.0	50 650	114 300[a]	21 300 000
Average for l/d = 3.0					152 500	
Average for l/d = 6.0					116 400[a]	20 700 000

[a] Not the ultimate strength of the material—specimen failed in bending.

TABLE III.—RESULTS OF TESTS OF SOLID AND HOLLOW TORSION SPECIMENS OF HIGH-STRENGTH CAST IRON.

Specimen Number	Outside Diameter, in.	Inside Diameter, in.	Ratio, $\frac{t}{r}$[a]	Maximum Twisting Moment, in-lb.	Modulus of Rupture, psi.	Maximum Shearing Unit Strain, in. per inch	Maximum Tensile Unit Strain, in. per inch	Shearing Modulus of Elasticity, psi.
1YTGS	0.749		1.000	4 470	54 200	0.0260	0.0130	8 250 000
1XTGS	1.000		1.000	10 410	53 000	0.0245	0.0123	8 150 000
1ZTGS	0.750		1.000	4 430	53 500	0.0231	0.0116	8 480 000
1WTGS	0.999		1.000	10 530	53 800	0.0249	0.0124	8 380 000
1WBGS	0.748		1.000	4 660	56 700	0.0283	0.0142	9 080 000
1ZBGS	1.000		1.000	11 380	58 000	0.0296	0.0148	8 760 000
1XBGS	0.749		1.000	5 320	64 500	0.0490	0.0245	8 250 000
1YBGS	0.998		1.000	11 910	61 000	0.0389	0.0195	8 420 000
Average, ¾-in. specimens					57 200	0.0316	0.0158	8 520 000
Average, 1.0-in. specimens					56 500	0.0295	0.0148	8 430 000
Average, upper part casting					53 800	0.0246	0.0123	8 320 000
Average, lower part casting					60 000	0.0386	0.0193	8 630 000
2WB5GS	Defective, not tested							
2XB4GS	Defective, not tested							
2XB2GS	0.750		1.000	5 020	60 600	0.0370	0.0185	8 850 000
2XB1GS	0.999		1.000	11 750	60 000	0.0399	0.0200	7 890 000
Average			1.000		60 300	0.0385	0.0192	8 370 000
2ZB5GH	Defective, not tested							
2YB4GH	1.000	0.315	0.685	9 110	46 900	0.0115	0.0078	8 450 000
2WB2GH	1.000	0.317	0.683	10 500	54 000	0.0273	0.0136	8 920 000
2YB1GH	0.999	0.312	0.687	10 930	56 400	0.0328	0.0164	8 260 000
Average			0.688		52 400	0.0252	0.0126	8 540 000
2XB5GH	1.000	0.499	0.501	8 520	46 300	0.0180	0.0090	8 800 000
2WB4GH	Defective, not tested							
2YB2GH	1.000	0.495	0.505	9 860	53 400	0.0280	0.0140	9 400 000
2ZB1GH	1.001	0.498	0.503	9 720	52 600	0.0280	0.0140	8 120 000
Average			0.503		50 800	0.0247	0.0123	8 770 000
2YB5GH	Defective, not tested							
2ZB4GH	1.000	0.751	0.249	5 300	39 600	0.0109	0.0055	8 690 000
2ZB2GH	1.000	0.754	0.246	5 790	43 600	0.0160	0.0080	8 440 000
2WB1GH	1.001	0.749	0.242	6 250	46 200	0.0235	0.0118	8 430 000
Average			0.246		43 100	0.0168	0.0084	8 520 000

[a] t = wall thickness; r = outside radius.

modulus of elasticity, determined in a definite, arbitrary way, shows no clearly defined manner of variation.

The differences between the properties of the solid and hollow specimens are no greater than those between the solid specimens themselves, a conclusion noted in a previous paper.[2] The average tensile strength is about 46,800 psi. as compared with 30,000 psi. for the irons reported upon previously. The maximum unit strain, however, appears to be slightly less, 0.0051 in. per inch as compared with about 0.0063 in. per inch for the low-strength irons. The modulus of elasticity of the high-strength iron is higher than that of the low-strength iron, 18,500,000 psi. as compared with an average of 13,400,000 psi.

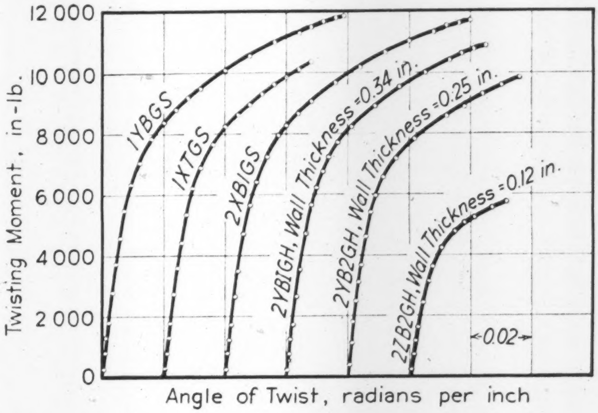


FIG. 6.—Typical Twisting Moment—Angle of Twist Curves for Solid and Hollow Torsion Specimens.

Compression Tests:

Compression tests were made on two lengths of specimens, $\frac{3}{4}$ by $2\frac{1}{4}$ in. and $\frac{3}{4}$ by $4\frac{1}{2}$ in. The shorter specimens, ratio of length to diameter $(l/d) = 3$, were tested for ultimate strength only and all failed in shear. Strain readings were taken on the longer specimens $(l/d = 6)$ and these all failed by bending. Consequently the ultimate strength of the material in the long specimens could not be found. The gage length was 2 in. and, in order to eliminate possible errors in the dial used on the compressometer and to maintain a high degree of sensitivity and accuracy, the compressometer was first calibrated for each two divisions on the dial. In the tests, the loads were read at the same dial divisions used in the calibration, and the calibration readings were used in computing the strains. The data are given in Table II and typical curves are shown in Fig. 5. It will be seen from Tables I and II that the average ultimate strength in compression is about 3.25 times the average ultimate strength in tension and that the modulus of elasticity in compression is about 1.13 times the modulus of elasticity in tension.

Torsion Tests:

Solid and hollow specimens having nominal wall thicknesses of $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{11}{32}$ in. and gage lengths of 5 in. were tested in a pendulum-type torsion machine. Twisting moment and twisting strain measurements were made at small increments of load to failure. The data are given in Table III and typical twisting moment – angle of twist curves are shown in Fig. 6. The curves are quite similar to those obtained for low-strength irons.

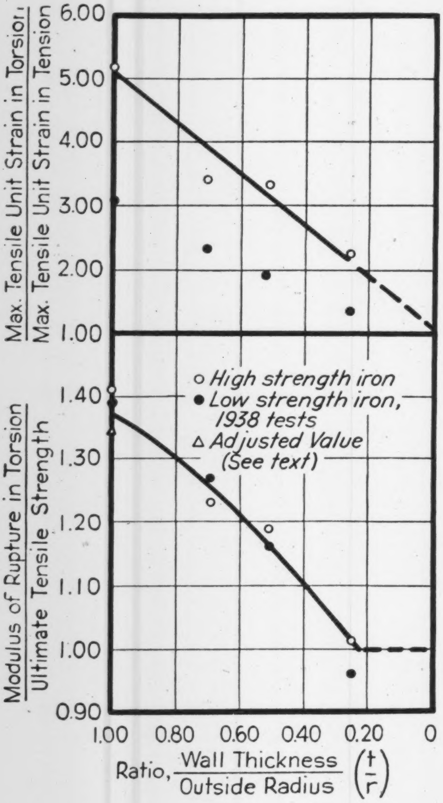


FIG. 7.—Curves Showing Relationship in Torsion Between Modulus of Rupture and $\frac{t}{r}$ and Between Maximum Tensile Unit Strain and $\frac{t}{r}$.

A comparison of the ratio of modulus of rupture in torsion to tensile strength and of the ratio of maximum tensile unit strain in torsion (maximum tensile unit strain is assumed to be one-half the maximum shearing unit strain) to maximum tensile unit strain in tension with the ratio of the wall thickness to the outside radius (t/r) is made in Fig. 7. The data for the low-strength irons are included in this graph but the curves drawn are for the high-strength iron only. The curves in Fig. 7 indicate that although the curves for the strength ratio (modulus of rupture in torsion to tensile strength) are about the same for both low-strength and high-strength irons, the curves for the deformation ratios (maximum tensile unit strain in torsion to maximum tensile unit strain in tension) are quite different even though they do have about the same shape. Since the high-strength iron has a higher strength at the bottom than at the top of the casting, an estimated average strength ratio is also plotted for the solid cylinder and this adjusted value is shown by a special symbol.

Repeated Torsion Tests:

Eight round solid specimens 0.300 in. in diameter and six round specimens 0.400 in. in diameter with a No. 60 drill hole (0.040 in. diameter) in them, Fig. 3 (*f*) and (*g*), were tested. The specimens were taken from the upper part of casting No. 1 (see Fig. 2) and, since they were smaller than the other specimens tested, their positions in the cross-section of the casting were slightly different from the positions of those tested in torsion under static loads. No specimens were cut from the center of the casting. The machine used for the repeated-load tests was designed at the University of Illinois.[4] The results of the tests are shown in Fig. 8. The endurance limit for the specimens without holes is about 16,000 psi. and for the specimens with holes it is 15,000 psi. As might be expected, the values are much less than the average modulus of

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[4] H. F. Moore and G. N. Krouse, "Repeated Stress (Fatigue) Testing Machines Used in the Materials Testing Laboratory of the University of Illinois," *Circular No. 23*, Engineering Experiment Station, University of Illinois (1934).

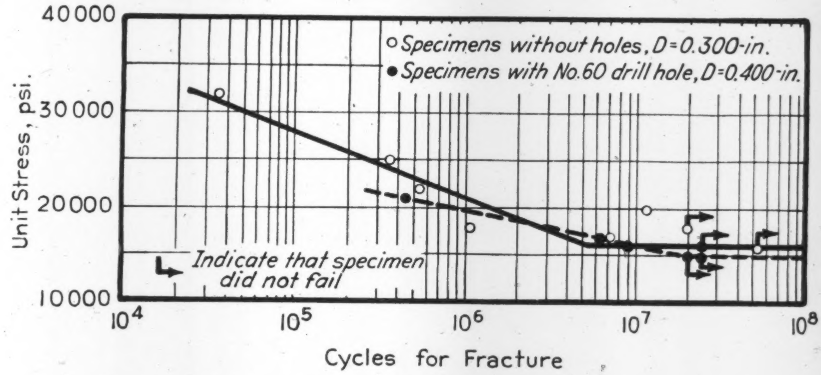

Fig. 8.—*S-N* Diagrams for Complete Reversals of Torsion Stress.

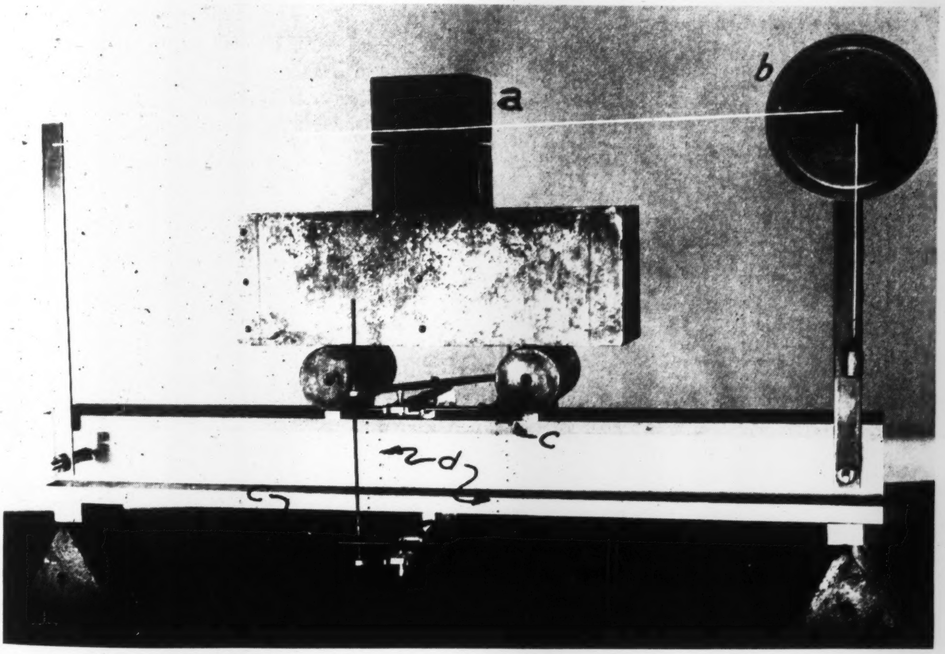

Fig. 9.—Photograph Showing H-Beam, Location of Gage Lines and Devices for Measuring Slope and Lateral Strain.

Due to the necessity of taking the photograph at an angle, there is a slight distortion of some vertical lines and an offset in the gage lines.

a = Loading block—spherical seat.
b = Wire-wound Wissler dial for measuring slope.
c = Martens' mirror for measuring lateral deformation.
d = Strain gage holes.

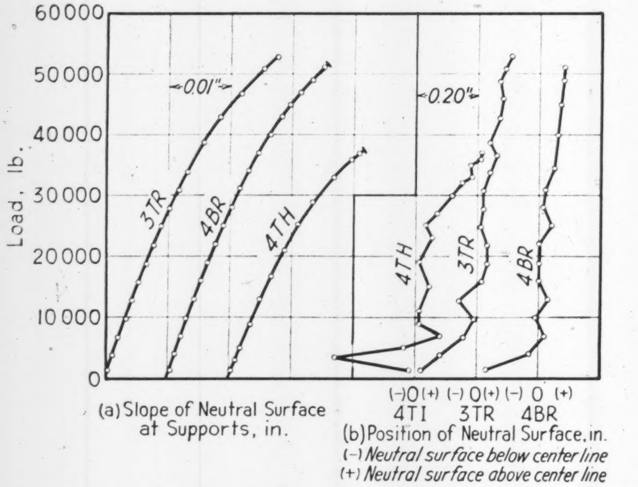

FIG. 10.—Curves Showing Relation Between Load and (*a*) Slope of Neutral Surface at Supports and (*b*) Position of Neutral Surface.

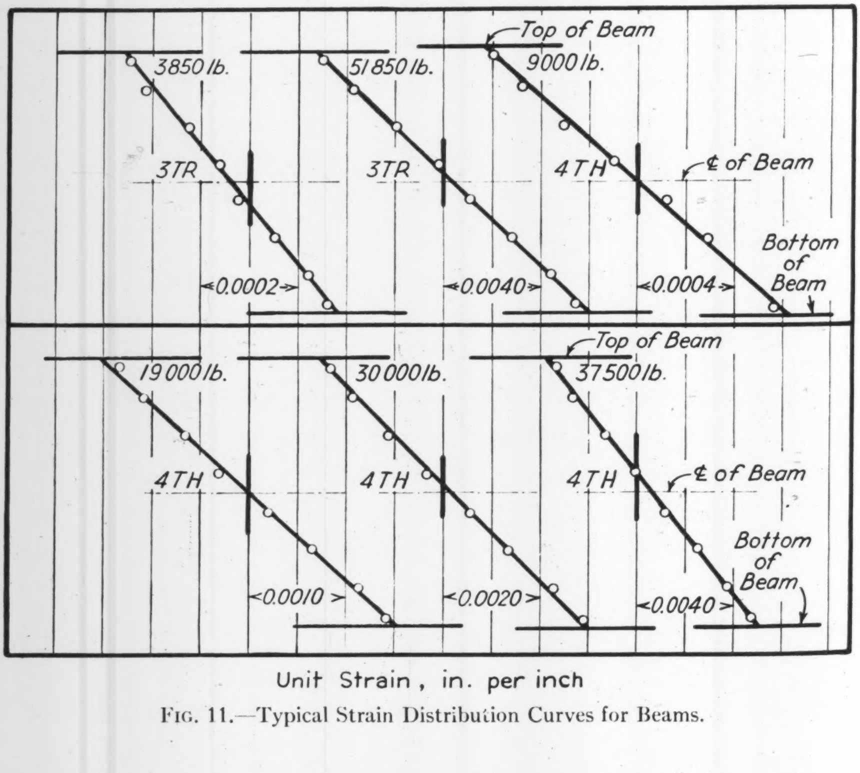

FIG. 11.—Typical Strain Distribution Curves for Beams.

rupture under static loading—which was 57,500 psi. The sensitivity to holes under repeated loading is much less than for most steels and is in accordance with the results generally observed in repeated stress tests of cast iron. The specimens all failed in tension with a helical fracture.

Bending Tests:

Two solid rectangular beams and one H-beam, all about $2\frac{3}{4}$ in. deep and $2\frac{3}{4}$ in. wide, were tested as simple beams. The span length was 24 in. and two loads 6 in. apart were placed symmetrically with respect to the center of the span. Strain-gage readings were taken, over a 4-in. gage length at eight gage lines on each side of the beam as follows: At load intervals of 3000 lb. for the rectangular beams and 2000 lb. for the H-beam in the earlier part of the tests and 1000 lb. for the rectangular beams and 500 lb. for the H-beam as the beams approached rupture. The lateral strains at the extreme top and bottom were measured over $2\frac{1}{2}$-in. gage lengths by an adaptation of two sets of Martens' mirror extensometers, each of which was calibrated for the position in which it was used. By means of vertical arms attached at the center of the depth of the beam at each support and a wire-wound Wissler dial, the slope of the ends of the beam was measured. No deflection readings were taken but the moduli of elasticity were computed from the slopes of the beams at the supports. Figure 9 shows the manner of loading, the location of the gage lines and the devices for measuring the lateral strain and the slope for the H-beam. Since the vertical arms were fastened to the beam only at the center of the depth, the readings could be influenced but little by horizontal shear, deformation of supports, or deformation of testing machine. The load-slope curves are shown in Fig. 10 (*a*). A summary of the observed and computed data are given in Table IV.

TABLE IV.—BEAM TESTS OF HIGH-STRENGTH CAST IRON.
Span = 24 in. Loads placed symmetrically with respect to center line and 6 in. apart.

Beam Number	Type and Dimensions	Maximum Load, lb.	Modulus of Rupture, psi.	Maximum Tensile Unit Strain, in. per inch	Maximum Compressive Unit Strain, in. per inch	Modulous of Elasticity, psi.
4BR........	Rect., 2.727 in. wide, 2.727 in. deep	51 800	69 000	0.00605	0.00520	19 900 000
3TR........	Rect., 2.726 in. wide, 2.726 in. deep	52 800	70 400	0.00642	0.00540	20 100 000
4TH........	H-beam, depth = 2.809 in., web = 0.507 in., flanges = 2.809 by 0.498 in.	37 500	59 200	0.00550	0.00380	21 100 000

In each plane where strains were measured, the readings on opposite sides of the beam were averaged and, using these averages, strain distribution curves for the cross-section were plotted for each loading. Typical curves for both rectangular and H-beams are shown in Fig. 11. Since no gage holes were drilled in either the extreme top or bottom of the beams, the average lines of the strain distribution curves were extended to the outside edges (top and bottom) of the beams and from these extrapolated values the load - longitudinal strain curves shown in Fig. 12 were drawn for the top and bottom "fibers" of each beam. Judging from the results of the tests in torsion and from some preliminary beam tests, it was expected that the maximum tensile unit strain in the "extreme fiber" of the beams might be considerably in excess of the values found in direct tension. The results, 0.00514 in. per inch in tension and 0.00624 in. per inch in bending, did not bear out this expectation; consequently it is planned to con-

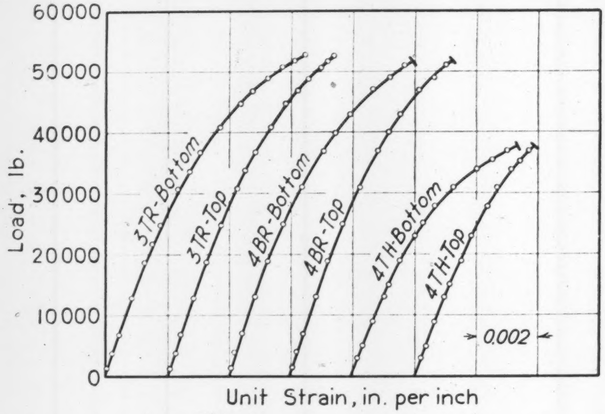

FIG. 12.—Curves Showing Longitudinal Unit Strain in Extreme Fibers of Beams.

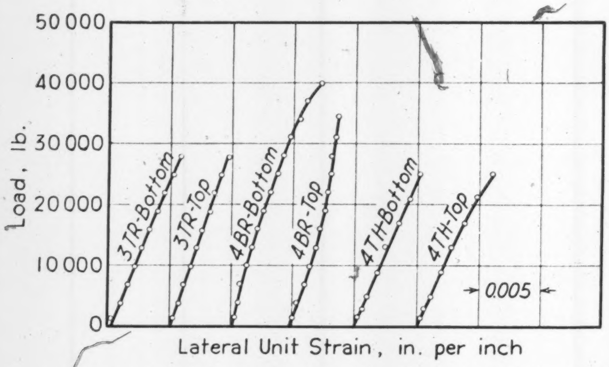

FIG. 13.—Curves Showing Lateral Unit Strain in Extreme Fibers of Beams.

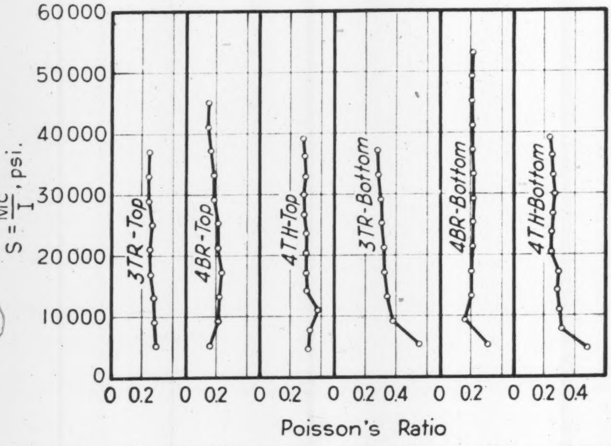

FIG. 14.—Curves Showing Poisson's Ratio for Extreme Fibers of Beams.

tinue these tests with beams of various span-depth ratios.

The shift in the position of the neutral surface as the load was increased is shown in Fig. 10 (*b*). Because of the small strains at the lower loads, the position of the neutral surface cannot be determined definitely and this fact should be kept in mind in interpreting Fig. 10 (*b*). However it is clear that the shift is relatively small for the rectangular beams but appreciable for the H-beam, being generally upward in all cases. The lateral strains for the top and bottom of each beam are shown in Fig. 13, and the relationship between the longitudinal and lateral unit strains at the tops and bottoms of the beams (Poisson's ratio) are shown in Fig. 14. It is believed that the curves for lateral strain are all equally reliable except that for the top of beam 4BR where, apparently, the mirror did not function properly. The values vary between about 0.20 and 0.30 in both tension and compression. Because of this variation it seems clear that considerably more work must be done before definite values can be stated for Poisson's ratio. This work will be continued on other beams.

TABLE V.—MECHANICAL PROPERTIES OF HIGH-STRENGTH CAST IRON.

Type of Stress	Number of Tests	Strength, psi.	Maximum Unit Strain, in. per inch	Modulus of Elasticity, psi.
Tension	20	46 800	0.00514	18 500 000
Compression:				
$l/d = 3$	4	152 500		
$l/d = 6$	6	116 400		20 700 000
Torsion, solid circular	10	57 500[a]	0.0161[b]	8 450 000
Repeated Torsion:				
Without hole	8	16 000[c]		
With No. 60 hole	6	15 000[c]		
Bending:				
Rectangular section	2	69 700[a]	0.00624[b]	20 000 000
H-section	1	59 200[a]	0.00550[b]	21 100 000

[a] Modulus of rupture. [b] Tensile unit strain. [c] Endurance limit.

Summary

Average values of the various mechanical properties of the high-strength cast iron used in these tests are shown in Table V. Complete comparison with values for similar tests on low-strength iron cannot be made because all of the tests of low-strength iron have not yet been made.

1. In tension and torsion, high-strength cast iron is quite similar in general action to low-strength cast iron.

2. The modulus of elasticity of the high-strength iron is nearly the same in compression and bending and slightly less in tension.

3. The modulus of elasticity in shear is about four-tenths the value in tension and compression.

4. The hole has relatively little effect on the endurance limit in completely reversed torsion.

5. The modulus of rupture for hollow circular specimens in torsion is less than for solid specimens, the ratio of the modulus of rupture to tensile strength being approximately unity for the ratio of wall thickness to outside radius (t/r) of 0.20.

6. The maximum tensile unit strain in torsion is greater than the maximum tensile unit strain in tension, the ratio decreasing as t/r decreases.

7. The modulus of rupture in bending is less for H-sections than for solid rectangular sections.

8. In a beam the neutral surface rises as the load is increased, the rise being greater in an H-beam than in a rectangular beam.

9. No single value was found which can be said to be the value of Poisson's ratio, either in tension or compression.

Acknowledgments:

Acknowledgment is made to H. R. Puckett, Research Assistant, Department of Theoretical and Applied Mechanics, University of Illinois, who assisted in making all of the tests and in reducing and plotting the data, to R. P. Molt, Senior Student in Engineering, who made the tests in repeated torsion, to Mr. J. T. MacKenzie of the American Cast Iron Pipe Co. for the chemical analysis of the iron and the photomicrographs in Fig. 1 (*c*), and to C. H. Casberg and J. F. Wooddell of the Machine Laboratories of the University of Illinois, who made the castings.

DISCUSSION

Mr. J. T. MacKenzie.[1]—We commonly run tests on cast-iron pipe, and some comparative results might be of interest. Straight tension tests on specimens cut from the wall of the pipe under our particular method of manufacture will run around 28,000 psi. In a beam test on a 15-ft. span on 6-in. pipe, with the third-point loading, the modulus of rupture will be about 36,000 psi., but if a strip is cut for transverse tests on 10-in. supports with third-point loading, the modulus of rupture is around 55,000 psi. I think that corroborates the authors' results quite well.

There is one question I should like to ask: In calculating the modulus of elasticity from the angle of movement of the ends, what assumption was made as to the bending curve of the beam?

Mr. H. F. Moore.[2]—You will note the point made in the paper to the effect that the drilling of a hole caused a rather serious theoretical stress concentration, but that it lowered the endurance limit only slightly. That effect is quite common with cast iron and other brittle materials. It is just an illustration that cast iron is a nonhomogeneous material which has a lot of internal "stress raisers," and to put in one more in the form of a hole does not do much additional damage.

Messrs. Jasper O. Draffin[3] **and W. L. Collins**[3] (*authors' closure by letter*).—We wish to thank Mr. J. T. MacKenzie for his comments regarding the beam tests of cast iron pipe and of specimens cut therefrom. The answer to his question about the assumption made regarding the bending curve (shape of the elastic curve) of the beam is that it was assumed to be in agreement with the results obtained from the general equation of the elastic curve of a beam, $M = EI\frac{d^2y}{dx^2}$ where M is the bending moment at any section, E is the modulus of elasticity of the material, I is the moment of inertia of the normal cross-sectional area with respect to the centroidal axis perpendicular to the plane of the loads, and $\frac{d^2y}{dx^2}$ is the rate of change of the slope of the elastic curve. For symmetrical two point loading, a single integration gives the following equation for the modulus of elasticity:

$$E = \frac{Pa(a - l)}{4I(dy/dx)}$$

where P is the total load, a is the distance between a reaction and the nearest load, l is the span length and $\frac{dy}{dx}$ is the slope at the support, the quantity measured in the experiment.

We also wish to thank Mr. H. F. Moore for emphasizing the difference between the theoretical and actual stress concentration factors caused by drilling a small hole in the repeated load specimens.

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[1] Chief Chemist, American Cast Iron Pipe Co., Birmingham, Ala.

[2] Research Professor of Engineering Materials, University of Illinois, Urbana, Ill.

[3] Professor, and Associate, respectively, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

INFLUENCE OF CHROMIUM ON THE OXIDATION RESISTANCE OF CAST IRON

By C. O. Burgess[1]

Synopsis

The primary object of the present investigation was to determine the effect of various chromium contents on the oxidation resistance of cast iron. Eleven cast irons containing approximately 0 to 25 per cent chromium were employed, and during 360-hr. exposure periods heated and cooled from test temperatures of 700, 800, 900, and 1000 C. A special technique was employed to insure comparable conditions and accurate determinations of weight gains. Data so obtained definitely indicate the percentage of chromium necessary at each temperature level to limit the total oxidation of cast iron. The progressive weight-gain curves at 800 and 900 C. establish the chromium content required to produce an adherent scale at these two temperature levels. Low-carbon control specimens indicate that carbon content has relatively little effect on oxidation resistance. The role of chromium in inhibiting oxidation is clearly brought out by the metallographic examination. The penetration of an oxidation constituent, provisionally designated as metal-oxide, beneath the metallic surface of cast irons low in chromium was noted, and is believed to shed some light on the little understood phenomenon of growth.

Following closely on the discovery that chromium limits the progressive oxidation of steel, various amounts of chromium have been added to cast iron in an attempt to improve its oxidation resistance. Particular significance attaches to such studies, as unalloyed cast irons are more subject to deterioration than steels on exposure to elevated temperatures. In addition to actual loss of metal through scaling, any pearlite or cementite existing in the iron is rapidly decomposed at elevated temperatures to ferrite and graphite and a cast part is subject to a progressive increase in volume or growth. Increases in volume of as much as 40 per cent have been recorded. These changes start at relatively low temperature; for example, growth has been reported on prolonged exposures of cast iron to temperatures as low as 300 C. The mechanism responsible for growth is imperfectly understood, the commonest hypothesis being that an initial small increase in volume results from the breakdown of any combined carbon present in the iron to the more voluminous ferrite plus graphite form, followed by penetration of oxygen into the iron, presumably along the graphite flakes. The flakes are then "swollen" through an accumulation of oxide products, and the iron casting as a whole further increases in volume. It is known that, in addition to objectionable distortion, an iron that has grown to an appreciable extent is extremely weak and brittle.

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[1] Research Metallurgist, Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y.

Chromium was found by various investigators to be the most effective of the common alloying elements both in inhibiting the breakdown of combined carbon in cast iron and in very materially decreasing the rate of growth up to maximum testing temperatures of 900 C. Additions of this element have been normally limited to approximately 1.5 per cent when it was necessary to retain machinability. However, as the temperature rises above approximately 600 C., even 1.5 per cent chromium, although considerably increasing the useful life of cast iron, does not appear to completely eliminate growth. At these higher temperatures also, the scaling of the iron appears as an increasingly important factor in determining the service life of the casting.

TABLE I.—ANALYSIS OF CAST IRONS.

Heat	Chemical Analysis, per cent							Flexual Properties 12-in. span	
	Total Carbon	Combined Carbon	Chromium	Silicon	Manganese	Phosphorus	Sulfur	Strength, lb.	Deflection, in.
				CAST IRON SERIES					
No. 4970	2.98	0.40	0.01	2.22	0.56	0.106	0.024	2900	0.08
No. 4971	2.98	0.63	0.54	2.21	...	...	...	4000	0.10
No. 4972	3.05	1.26	1.06	2.28	...	...	...	2900	0.09
No. 4973	3.09	2.98	1.99	2.32	...	...	...	3100[a]	0.06
No. 4974	3.08	...	3.81	2.46	...	...	...	2700	0.05
No. 4975	3.10	...	6.15	2.52	...	...	...	2100	0.04
No. 4976	3.03	...	8.27	2.53	...	...	...	3500	0.06
No. 4977	2.88	...	11.00	2.45	...	...	...	3100	0.06
No. 4978	2.92	...	13.28	2.66	...	...	...	4200	0.07
No. 4979	2.90	...	17.06	2.40	0.66	0.103	0.023	2900[a]	0.05
No. 4980	2.94	...	25.18	2.40	...	...	...	4900	0.07
				COMPARISON SPECIMENS					
No. 1	0.13	...	17.56	0.31	0.38	less than 0.03	less than 0.03	...	...
No. 2	0.12	...	27.25	0.42	1.00	0.03	0.03	...	...

[a] Result probably affected by defects.

Obviously a need exists for specific information as to the quantity of chromium necessary to limit oxidation of cast iron at high temperatures. Unfortunately our data on low-carbon chromium irons or steels cannot be directly translated into terms of cast iron, as cast irons by definition have considerably higher carbon contents, and carbon, because of its affinity for chromium and the consequent formation of chromium and iron-chromium carbides, drastically influences the reaction of chromium-bearing materials to outside influences. In addition, the silicon content of a cast iron base is usually higher than that of low-carbon or wrought materials. Some scattered information on the oxidation resistance of chromium-bearing cast irons is available and, strangely enough, does not indicate a sacrifice in oxidation resistance despite removal of chromium from solid solution in the form of complex carbides. In fact, if the results of the most recent work by Thyssen[2] are plotted, the gain in weight due to oxidation of irons containing 15 to 40 per cent chromium after 150 hr. exposure at 950 C. (1740 F.) appears actually to decrease somewhat as the carbon rises from 1 to 3 per cent.

The tests outlined in the present paper were consequently undertaken to supply information as to the quantity of chromium necessary to limit scaling of a cast iron to a given value at four different temperature levels, namely, 700, 800, 900, and 1000 C. The effect of extended exposure at these temperatures on the structure of the irons was also determined in view of the known influence of these changes on the useful life of cast iron. It was likewise felt that examination of the exposed irons might yield some clue regarding the remarkable ability of chromium to limit growth outside of its known carbide stabilizing action, and to furnish some general information on the phenomenon of growth.

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[2] H. Thyssen, "Contribution a l'étude des fontes au chrome," *Transactions*, Congrés Internat. de Fonderie, Vol. 24, 15 pp. (1938).

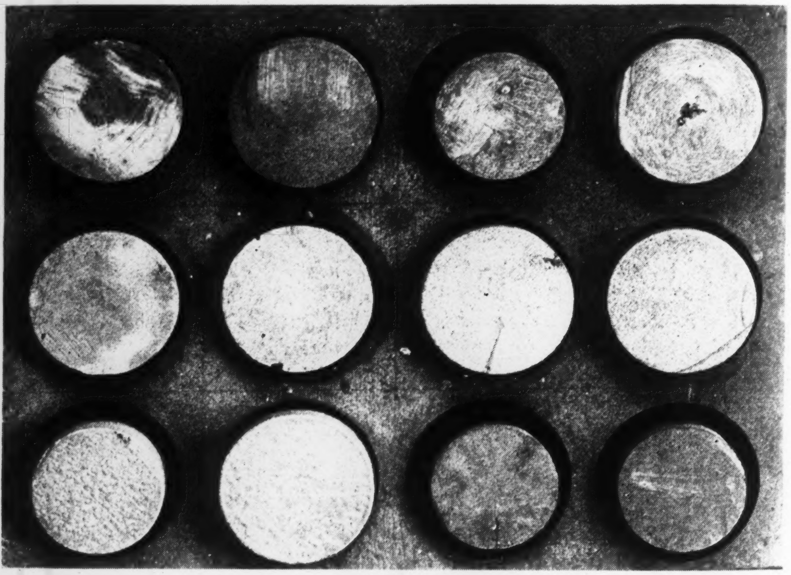


FIG. 1.—Assembly Used in Oxidation Tests (× $\frac{3}{4}$).

MATERIALS

A cast iron base material analyzing approximately 3.00 per cent carbon, 2.25 per cent silicon, 0.60 per cent manganese, 0.11 per cent phosphorus, and 0.03 per cent sulfur was selected. Chromium was added in increasing amounts to this base. The analyses of the eleven resultant irons covering a chromium range from 0.01 per cent to 25.18 per cent are shown in Table I. Included in this table are the anlyses of two low-carbon wrought steels containing approximately 17.5 and 27 per cent chromium used for comparison.

The irons were cast in the form of standard $1\frac{1}{8}$-in. diameter transverse bars. Following flexure tests, the bars were sandblasted, and slices approximately $\frac{1}{2}$ in. thick were cut from the bars. These slices, approximately $1\frac{1}{8}$ in. in diameter and $\frac{1}{2}$ in. thick, were used as oxidation specimens. In a few cases in the tests at 700 and 1000 C., specimens ground to 1 in. in diameter were employed, but this difference in size did not influence the results as the degree of oxidation was based on the loss or gain in weight per square centimeter of surface. The two low-carbon oxidation specimens were cut from wrought 1-in. diameter bars.

TEST METHODS

The flexure tests, the results of which are shown in Table I, were made on a 12-in. span. A special experimental method was devised for the oxidation tests, both to insure comparable test conditions in the case of each specimen of a series, and to enable a study to be made of progressive oxidation. A $\frac{1}{2}$-in. thick plate of a 25 per cent chromium, 12 per cent nickel alloy was selected, and sufficient holes $1\frac{3}{8}$ in. in diameter and $\frac{1}{4}$ in. in depth were drilled in the plate to accommodate the eleven specimens of the cast iron series and the two low-carbon specimens. A specimen of each of the irons was inserted in these pockets, and the plate and specimens brought to the desired test temperature in an electric muffle furnace. Figure 1 illustrates the appearance of a section of the assembly containing the test specimens after 360 hr. exposure at 700 C. The use of the plate furnished assurance that all the specimens reached an equal temperature. Setting the samples in depressions facilitated accurate determination of the progressive gain in weight due to oxidation, as the oxidation products breaking off from each specimen collected in the pocket in which the specimen was inserted and could be removed and weighed together with the specimen. Oxidation of the side surfaces of the specimens was found to be uniform from top to base, the clearance between the specimens and the sides of a pocket being sufficient to admit air freely.

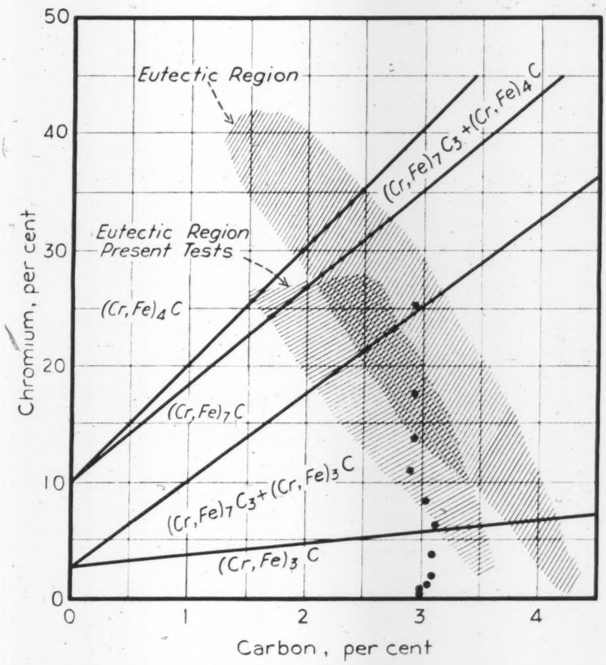
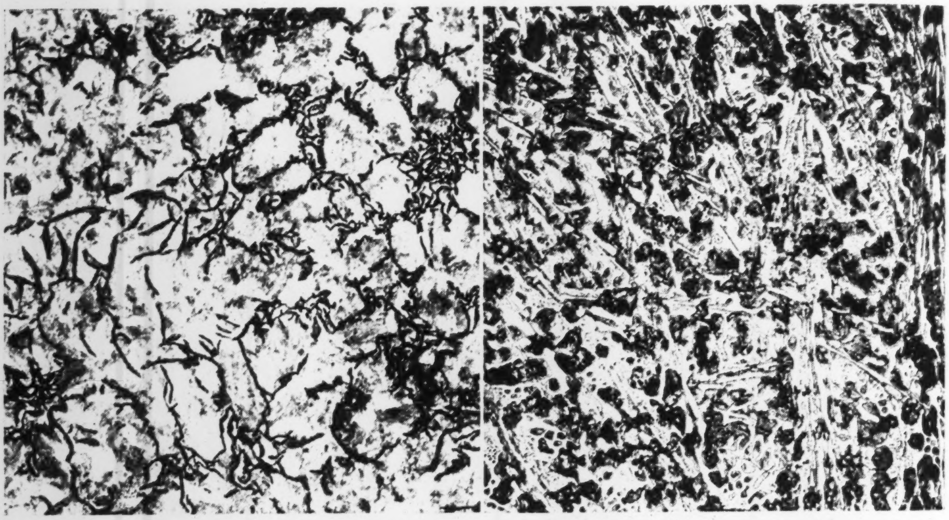


FIG. 2.—Location of Present Cast Iron Series in Reference to Eutectic Region.

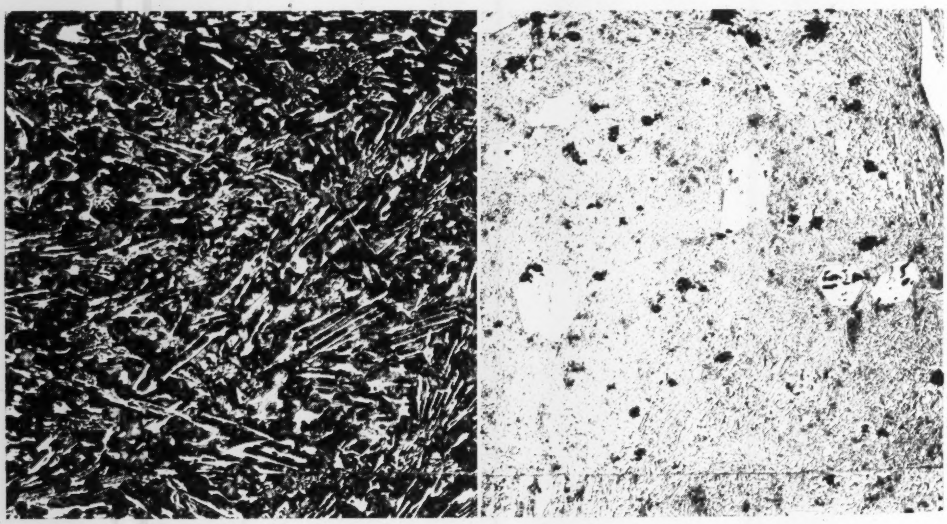
TEST DATA

It is clear from the analyses of the irons in Table I that the combined carbon in the base iron increases with chromium content, so that when the chromium content reaches approximately 2 per cent, the iron is almost completely white. Metallographic examination of the still higher chromium irons of the series shows them to be completely free from graphite, as cast.

The flexure values in Table I show the usual improvement with a small addition of chromium. After the chromium exceeds 2 per cent, a progressive decrease in flexural properties takes place until a content of 8.27 per cent chromium is reached, when both the flexural strength and deflection again improve. This behavior, namely, an improvement in mechanical properties as the chromium exceeds a certain critical value, is typical of high chromium cast irons. As



(*a*) Heat No. 4970 (0.01 per cent Chromium). (*b*) Heat No. 4974 (3.81 per cent Chromium).



(*c*) Heat No. 4976 (8.27 per cent Chromium). (*d*) Heat No. 4980 (25.18 per cent Chromium).

FIG. 3.—Variation in As-Cast Structure of Irons at Three Chromium Levels (× 100).

can be seen from Fig. 2, it corresponds to the point of entrance into the eutectic zone and the point at which a marked refinement of the carbides takes place. This figure is plotted from data by Tofaute and coworkers, and the shifting of the eutectic zone due to the presence of 2.25 per cent silicon in the present irons is shown. The refinement in the eutectic region is readily recognizable in the fractures of the transverse bars, coarse bright fracture altering to a dull, fine-grained fracture when the chromium content reaches 8.27 per cent, and continuing fine through the 17.06 per cent chromium iron. The last iron of the series containing 25.18 per cent chromium is slightly hypereutectic, and bright needles make their appearance in the fracture. It is evidently not sufficiently hypereutectic, however, to affect adversely its flexural properties.

Figure 3 illustrates the normal gray iron structure of the unalloyed iron, the complete disappearance of graphite when the chromium content reaches 3.81 per cent, the refinement in carbides as the eutectic region is reached at 8.27 per cent chromium, and the appearance of hypereutectic carbides when the chromium content rises to 25.18 per cent. The pearlitic ground mass of the irons becomes increasingly finer with increase in chromium and finally assumes a sorbitic appearance unresolvable at 500 diameters in heat No. 4979 containing 17.06 per cent chromium.

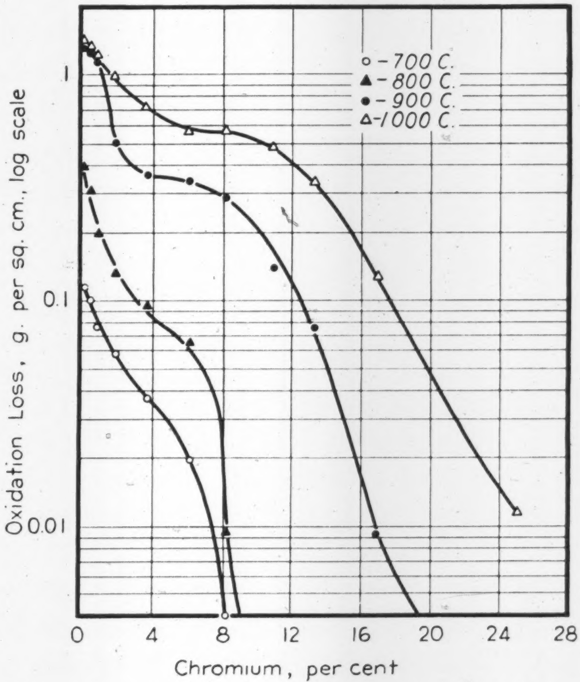


FIG. 4.—Oxidation Loss as a Function of Chromium Content.

The eleven irons in this series were exposed in air for a total of 360 hr. at temperatures of 700, 800, 900, and 1000 C. In each case the exposure period was interrupted and the specimens allowed to cool to room temperature after 24, 72, 120, 168, 216, 264, and 312 hrs. This was done to permit loosening or flaking off of any non-adherent scale such as might occur in service. No attempt, however, was made to remove scale mechanically. At the conclusion of the 360-hr. test periods, all adhering scale was removed from the specimens by careful sandblasting. Their change in weight was determined and the oxidation loss calculated on the basis of grams lost per square centimeter of original area.

The resultant curves of oxidation loss as a function of chromium content are shown in Fig. 4. Because of wide differences in the total amount of oxidation between 700 and 1000 C., it was necessary to plot oxidation loss on a logarithmic scale. A minimum loss of 0.004 g. per sq. cm. was selected as a base, as weight determinations of less than this amount were felt to be within the limits of experimental error. Assuming progressive oxidation at the rate of 0.004 g. per sq. cm. in 360 hr. a specimen would show a loss slightly less than 0.10 g. per sq. cm. per yr. corresponding to the formation of an extremely thin surface scale. Actually, as is subsequently brought out, the oxidation loss with increased time would be considerably less than this amount.

Several interesting features may be noted in the curves. First a definite knee is evident in the curves representing tests at 800, 900, and 1000 C.; that is, after a relatively rapid increase in oxidation resistance with increasing chromium a range is reached in which further increase in chromium confers a lesser relative increase in resistance, but when a critical percentage of chromium is exceeded—approximately 6 per cent at 700 C., 8 per cent at 900 C., and 11 per cent at 1000 C.—the degree of relative improvement in oxidation resistance with chromium content again increases. Secondly, an apparent maximum oxidation loss for unalloyed or chromum irons with up to 1 per cent chromium is established, the total oxidation loss at 900 and 1000 C. being very similar, and a marked difference in total oxidation loss at these two temperatures being evident only when approximately 2 per cent chromium is present.

The oxidation loss of the low-carbon alloys Nos. 1 and 2 are shown below, together with the two cast irons most nearly comparable in chromium content:

Heat	Carbon, per cent	Chromium, per cent	Total Loss, g. per sq. cm.			
			700 C.	800 C.	900 C.	1000 C.
No. 1	0.13	17.56	0.001	0.001	0.013	0.222
No. 4979	2.90	17.06	0.003	0.001	0.009	0.124
No. 2	0.12	27.25	0.001	0.001	0.003	0.009
No. 4980	2.94	25.18	0.002	0.001	0.001	0.011

As previously stated, weight readings of losses under 0.004 g. per sq. cm. are believed to be within our experimental error. It is clear however, that the high-carbon 17.06 per cent chromium cast iron (heat No. 4979) is actually superior in oxidation resistance to the low-carbon 17.56 per cent chromium alloy at 900 and 1000 C. The high-carbon 25.18 per cent chromium cast iron (heat No. 4980), on the other hand, appears approximately equal in oxidation resistance to the low-carbon 27.25 per cent chromium alloy. Although high silicon content undoubtedly contributes to the resistance of the cast irons, it appears that a carbon content as high as 3 per cent does not materially lower the oxidation resistance of chromium-bearing irons.

In addition to the above tests, the gain in weight after 24, 72, 120, 168, 216, 264 and 312 hr. exposure was actually determined at the 800 and 900 C. test temperatures. The gain in weight included all scale adhering to the specimen as well as any oxidized material that spalled off during cooling. It is at once evident from these tests that total oxidation losses measured over a definite period, such as are recorded in Fig. 4, do not represent in the case of the chromium-bearing irons a uniform rate of oxidation over the test period. Figure 5, a typical section of the weight-gain curves, illustrates this point. It is evident from these abbreviated curves that the rate of oxidation was not uniform. Even the unalloyed iron at 800 C. shows a relatively rapid rate of oxidation accompanied by the formation of a partially protective oxide coating after which oxidation proceeds at a somewhat decreased rate. In the case of the 0.54 per cent chromium cast iron, the amount of preliminary oxidation before a decreased oxidation rate sets in is definitely less, but the final or secondary rates of oxidation of the unalloyed and 0.54 per cent chromium iron appear approximately the same. On the other hand, with 1.06 per cent chromium present the initial oxidation and the more important secondary rate of oxidation are both reduced. In other words, with continued testing, the weight-gain curves of the plain and 0.54 per cent chromium cast irons are steeper and depart farther and farther from the weight-gain curve of the 1.06 per cent chromium cast iron. With 1.99 per cent chromium, the preliminary and secondary oxidation rates show an even more marked decrease. This form of the weight-gain curves is typical; that is, a relatively rapid oxidation during the first 72-hr. or 120-hr. period of the test followed by a distinctly decreased rate of oxidation up to 360 hr. One of the most striking features was that this secondary rate of oxidation, once set up, was quite uniform throughout the remaining period of the test. Naturally the initial oxidation with the higher chromium alloys was very slight; for example, at 800 C. the total oxidation or weight gain in the first 72 hr. was less than 0.005 g. per sq. cm. for irons containing 11.0 per cent or more chromium, and the secondary rate of oxidation approached zero. It is clear, particularly in the case of irons containing 1.99 per cent or more chromium, that if the total oxidation over a given period is desired, the total loss over the 360-hr. period of Fig. 4 should not be directly multiplied by the number of hours in the selected period of exposure. For example, if a loss of 0.004 g. per sq. cm. is shown in 120 hr. by a given chromium-bearing cast iron, the oxidation loss in 360 hr. will not be three times as great, namely, 0.012 g. per sq. cm. In fact, such longer exposure may not appreciably increase the loss over the original 0.004 g. per sq. cm. shown at 120 hr. The converse of course is true, that if an installation can be conceived in which the scale is com-

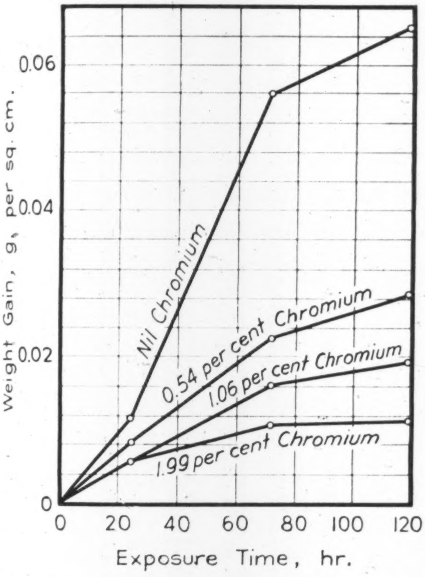


FIG. 5.—Oxidation of Cast Irons at 800 C.

pletely removed periodically by means other than heating and cooling to the test temperature, the oxidation may exceed that shown in Fig. 4.

It is possible from the weight-gain curves plotted over a 360-hr. period to determine the percentage of chromium necessary to establish an adherent or oxidation-resistant scale and to reduce progressive oxidation to a negligible value. Thus at 800 C., although the total oxidation was materially reduced at 0.54 per cent and 1.06 per cent chromium, at 1.99 per cent chromium 60 per cent of the total weight gain occurred in the first 72 hr. and from this point to the 360 hr. the rate of weight gain fell to one-fifth of that shown in the first 72 hr. With 8.27 per cent chromium, the efficiency of the protective scale was almost perfect, 86 per cent of the total weight gain occurring in the first 72 hr., and the secondary rate of weight gain dropping to one-twentieth of that shown during the first 72 hr. With 11 per cent chromium, 94 per cent of the weight gain occurred in the first 120 hr. It is immediately evident from this study that if an oxide coating can be maintained in any particular application, 1.99 per cent chromium will yield an improvement much greater than indicated by the total oxidation loss curves of Fig. 4, and that 8.27 per cent chromium will normally yield almost complete oxidation resistance at 800 C.

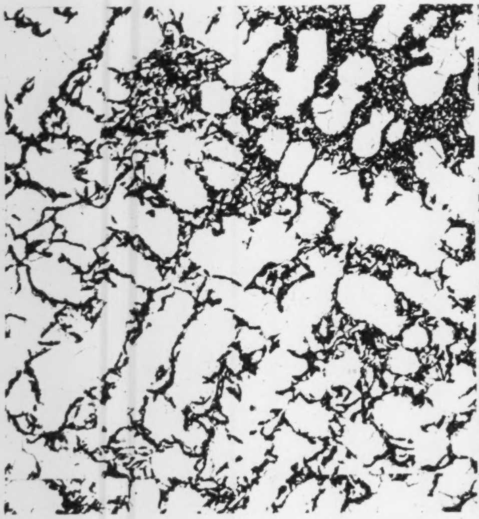


FIG. 6.—Heat No. 4970 (0.10 per cent Chromium) at 700 C. (× 100).

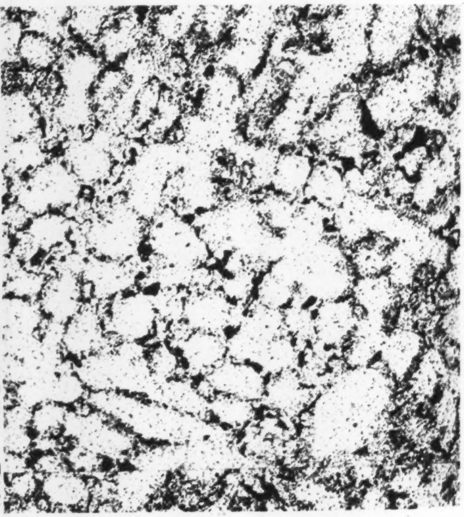


FIG. 7.—Heat No. 4971 (0.54 per cent Chromium) at 700 C. (× 100).

At 900 C., the weight-gain curves (not shown) show one marked difference in that the unalloyed and 0.54 per cent chromium cast irons show no tendency to form a protective scale, the weight gain being uniform throughout the 360-hr. test period. The first tendency toward a decreased secondary oxidation rate was evident in the 1.06 per cent chromium specimen but again, as in the 800 C. tests, the most marked decrease occurred on reaching a chromium content of 1.99 per cent. At this chromium content, approximately 60 per cent of the total weight gain occurred in the first 120 hr., the secondary oxidation rate being one-third to one-fourth that in the first 72 hr. As would be expected, both the total weight gain and the rates in the two periods were approximately 6 times as great as at 800 C. It is interesting, however, to observe that at both 800 and 900 C. the presence of 1.99 per cent chromium produces a very sharp change in the rate of secondary oxidation, and it can be assumed that sufficient chromium is present in the cast iron to alter the oxidation resistance materially. Although appreciable improvement as regards lowering this secondary rate of weight gain occurs with further increase in chromium, approximately 17.06 per cent chromium is necessary at 900 C. to reduce the secondary oxidation rate to almost zero, as compared to 8.27 per cent chromium at 800 C. Again it can be concluded that as little as 1.99 per cent chromium will very materially improve oxidation resistance at 900 C., but 17.06 per cent chromium is necessary to yield almost complete oxidation resistance.

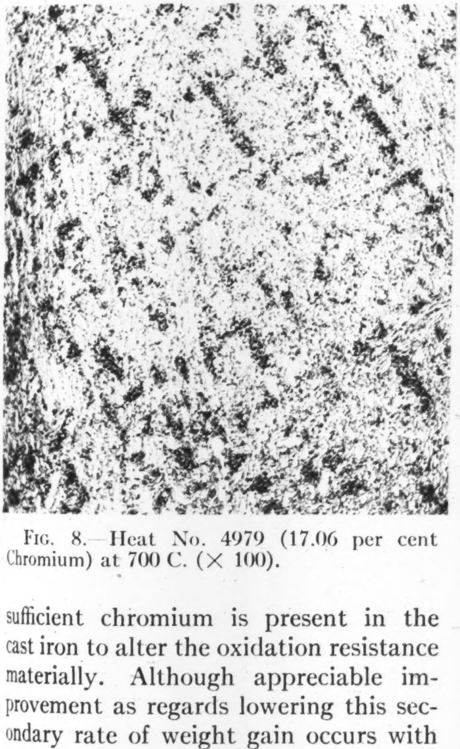


FIG. 8.—Heat No. 4979 (17.06 per cent Chromium) at 700 C. (× 100).

It is, of course, not possible to estimate accurately the effect of protective coatings at the 700 and 1000 C. levels. It is reasonable to assume however, from the curves of Fig. 4, that at 700 C., 8.27 per cent chromium will produce a completely resistant coating, and probably lower chromium contents such as 6.15 per cent might furnish full protection. At 1000 C. it is probable that the chromium content should approach the maximum of 25.18 per cent for full protection.

METALLOGRAPHIC EXAMINATION

Following the oxidation tests at the four test temperatures and sandblasting to remove all adhering scale, the specimens were sectioned along a center line and submitted to metallographic examination.

The "as cast" structure of this series has been already described and typical structures illustrated in Fig. 3. Graphite disappears with increasing chromium, only traces being left when the chromium reaches 1.99 per cent in the present base iron. If this same series is exposed to 700 C. for 360 hr. and examined, it is found that the combined carbon of the pearlite is totally broken down in the unalloyed iron heat No. 4970 as illustrated in Fig. 6, only ferrite and graphite in coarse flake and fine eutectic forms remaining. As can be seen in Fig. 7, as little as 0.54 per cent chromium is sufficient to stabilize small areas of primary cementite and fine globules of cementite resulting from spheroidization of the pearlite. Figure 8 illustrates the fact that the primary carbides are unaffected in the higher chromium irons, heat No. 4979 (17.06 per cent chromium), although some spheroidization of the carbides of the ground mass takes place. One interesting observation is that at least a small amount of temper carbon can be precipitated in both the 1.99 and 3.81 per cent chromium cast irons on extended holding. This is illustrated in the unetched photomicrograph of Fig. 9.

After exposure to 800 C., traces of sorbitic-pearlite appear in the ferritic background of the unalloyed iron due to re-solution of carbon above the critical point, and the amount of this constituent increases in the 0.54 per cent chromium cast iron, as seen in Fig. 10. When the chromium reaches 1.99 per cent the critical point is apparently sufficiently raised so that no re-solution of carbide takes place, the spheroidized carbides from pearlitic cementite merely increasing in size in this latter sample. Figure 11 illustrates the structure of the 17.06 per cent chromium sample after this exposure.

After the 900 C. exposure, only a small central zone of the unalloyed specimen consists of ferrite and some pearlite. The outer part of the specimen contains a constituent designated as a metal-oxide layer, which will be subsequently described. At this higher temperature, specimens containing up to 8.27 per cent chromium show re-solution of carbides and the production of a completely pearlitic ground mass interspersed with primary cementite. With 11.0 per cent chromium, Fig. 12, there is less complete solution of carbide and considerable ferrite remains. With 13.28 per cent chromium, Fig. 13, sorbite almost disappears, and with 25.18 per cent chromium, Fig. 14, there is practically no re-solution of carbides although the ferrite appears discolored. Progressive raising of the critical point by high chromium is the most logical explanation for this lack of solubility.

At 1000 C. there is little change in

FIG. 9.—Heat No. 4974 (3.81 per cent Chromium) at 700 C. (× 100).

the internal structure of the lower chromium irons. The solubility for carbide becomes greater with increase of temperature in the 11.00 and 17.06 per cent chromium cast irons so that they become sorbitic throughout. Even a slight degree of carbon solubility is exhibited by the 25.18 per cent chromium specimen.

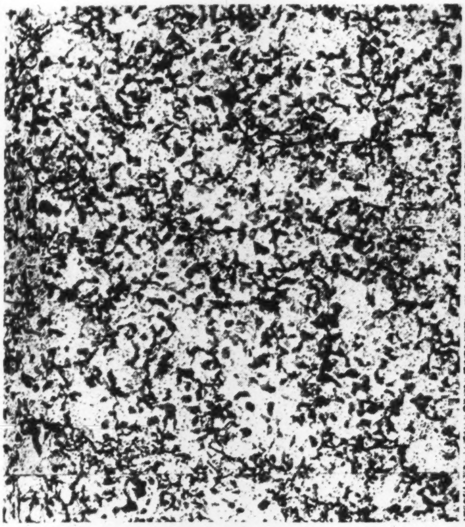


FIG. 10.—Heat No. 4971 (0.54 per cent Chromium) at 800 C. (× 100).

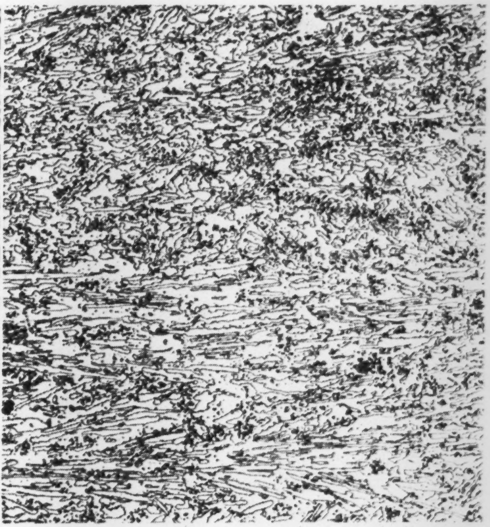


FIG. 11.—Heat No. 4979 (17.06 per cent Chromium) at 800 C. (× 100).

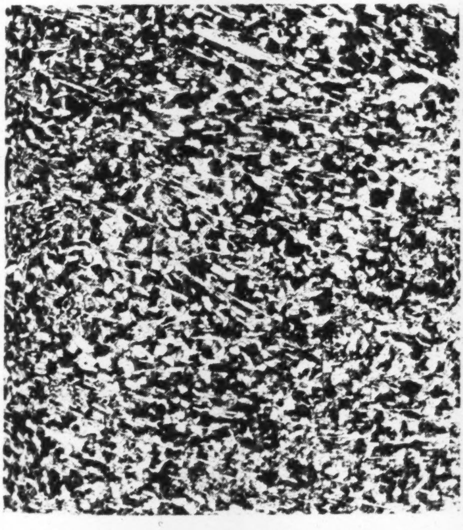


FIG. 12.—Heat No. 4977 (11.00 per cent Chromium) at 900 C. (× 100).

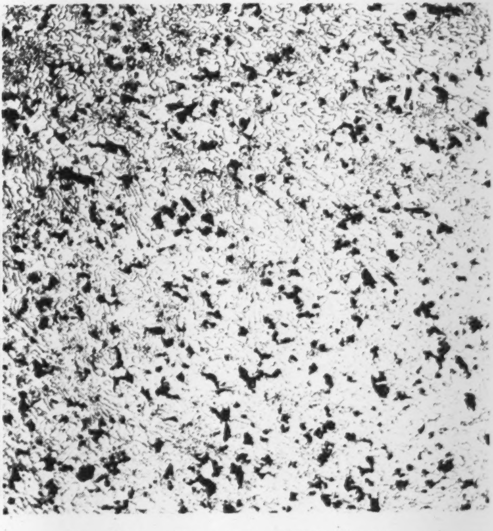


FIG. 13.—Heat No. 4978 (13.28 per cent Chromium) at 900 C. (× 100).

It should be stressed that except at the extreme edge, no appreciable alterations in the primary needles or areas of cementite occurred at any of the test temperatures when the chromium reached 1.99 per cent or more, the changes taking place involving spheroidization and solution of the pearlitic cementite. It is very clear that the cementite of the pearlite is different from the primary cementite in composition, the former undoubtedly being lower in chromium content.

FIG. 14.—Heat No. 4980 (25.18 per cent Chromium) at 900 C. (× 100).

A particular study was also made of the alterations that occurred adjacent to and at the surface of oxidation specimens. It was found that a chromium content exists for each exposure temperature at which there is no alteration in the structure of the sample from the center to the extreme edge. At 700 C. an extremely thin ferrite edge is evident with a chromium content of 1.99 per cent and all evidences of deoxidation disappear at 6.15 per cent chromium, as can be seen in Fig. 15. At 800 C., the ferrite edge also becomes narrow at 1.99 per cent chromium but does not completely disappear until 8.27 per cent chromium is reached. At 900 C. the ferrite layer is thin (0.004 in.) with 3.81 per cent chromium and completely disappears at 13.28 per cent chromium. At 1000 C. a thin ferrite edge is present at the 3.81 per cent chromium level and

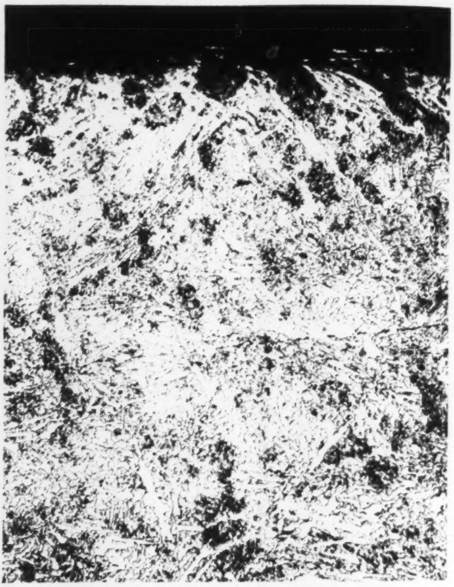


FIG. 15.—Heat No. 4975 (6.15 per cent Chromium) at 700 C. (× 100).

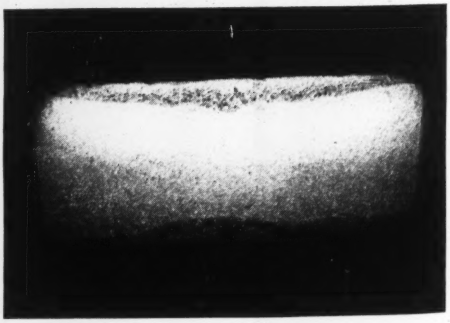
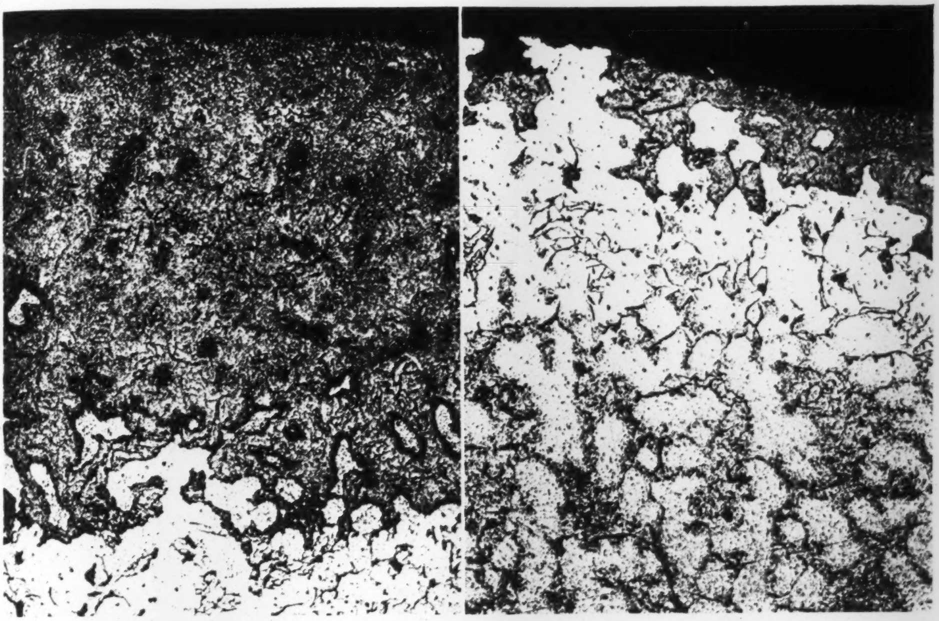
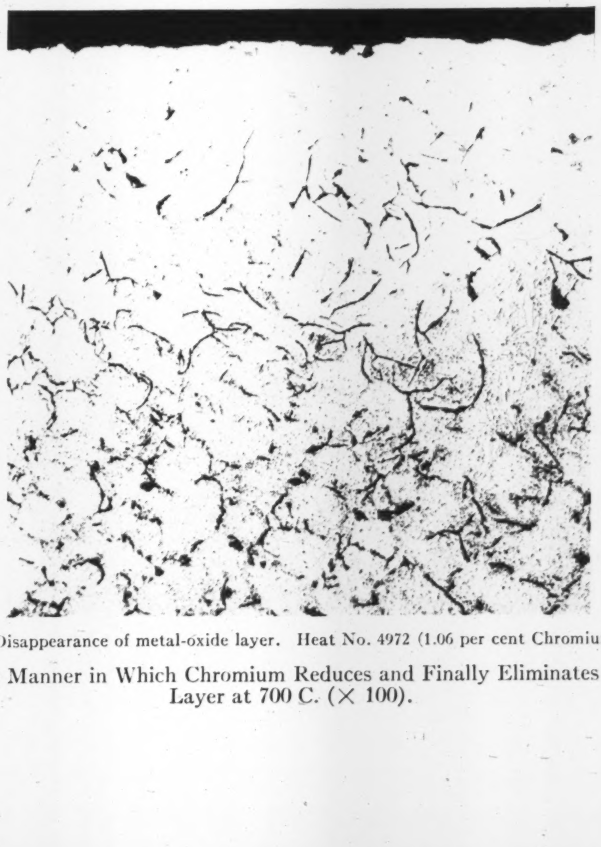


FIG. 16.—Heat No. 4970 (0.01 per cent Chromium) at 800 C. (× 2).



(*a*) Metal-oxide layer. Heat No. 4970 (0.01 per cent Chromium).

(*b*) Reduction of metal-oxide layer. Heat No. 4971 (0.54 per cent Chromium).



(*c*) Disappearance of metal-oxide layer. Heat No. 4972 (1.06 per cent Chromium).

FIG. 17.—Showing Manner in Which Chromium Reduces and Finally Eliminates the Metal-Oxide Layer at 700 C. (× 100).

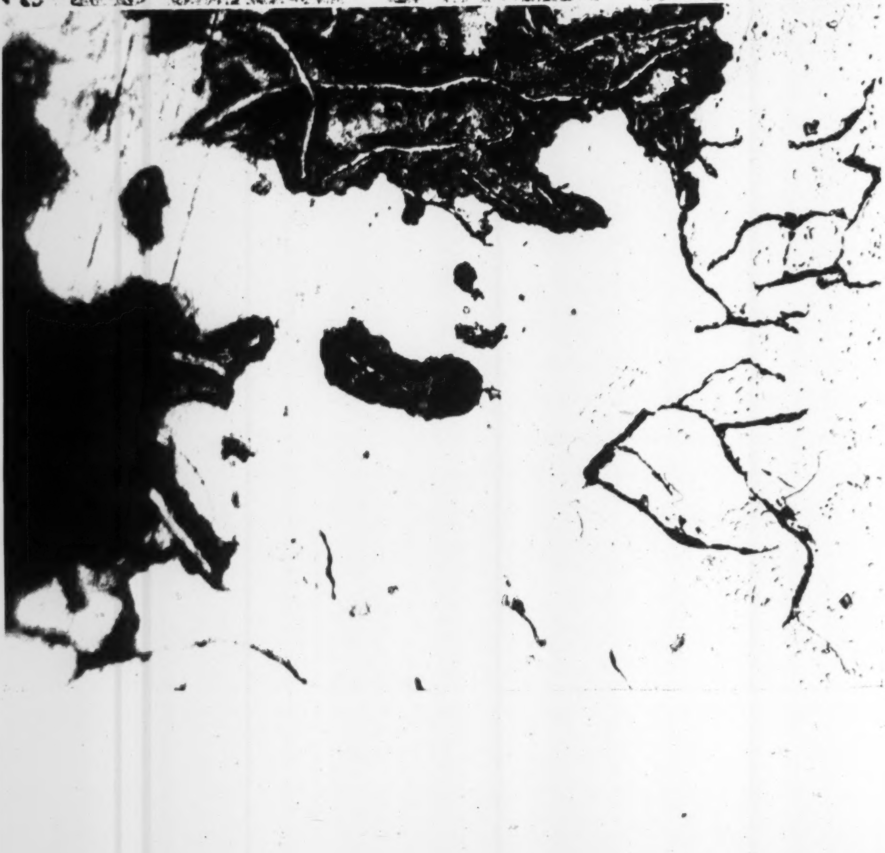


FIG. 18.—Metal-Oxide Extending from Scale. Heat No. 4971 (0.54 per cent Chromium) at 700 C. (× 500).

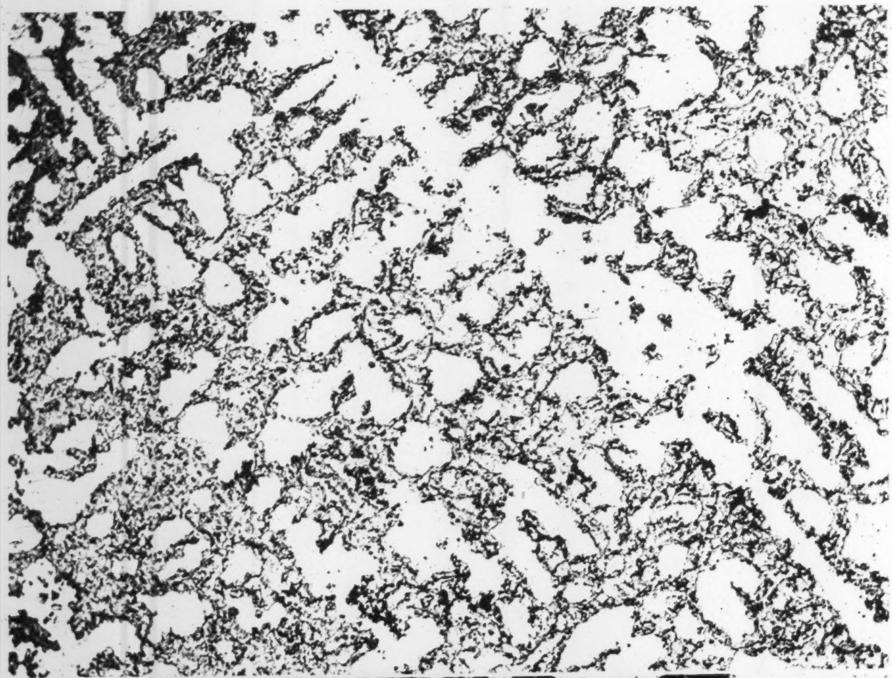


FIG. 19.—Metal-Oxide Layer. Heat No. 4970 (0.01 per cent Chromium) at 900 C. (× 100).

is not completely eliminated until the chromium reaches 17.06 per cent.

METAL-OXIDE CONSTITUENT

Probably the most interesting observation, however, was that a certain constituent makes its appearance close to the surface of oxidation specimens low in chromium content. The occurrence of this constituent can be reduced or eliminated by chromium additions. For example the constituent was absent in all specimens, even those held at 1000 C., when the chromium reached or exceeded 1.99 per cent. The formation and degree of penetration of this constituent would appear to explain the growth of cast iron.

The constituent is definitely associated with the oxidation process but is clearly metallic in character and is not scale. It will be recalled that all adhering scale was removed by sandblasting. As a consequence the name "metal-oxide" or "metal-oxide layer" is believed to be most descriptive. Figure 16 illustrates the formation of this layer on the unalloyed iron heat No. 4970, after 360 hr. at 800 C. This specimen was etched to accentuate the layer. It is much less visible in the unetched condition, appearing merely as a slightly roughened area. The manner in which chromium reduces and finally eliminates the metal-oxide layer at 700 C. is shown in Fig. 17. It was not possible to re-

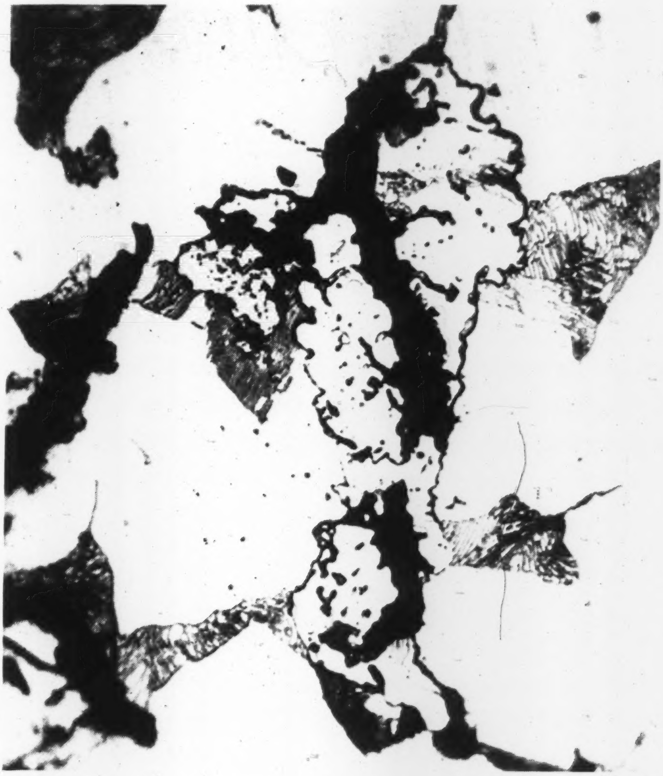


FIG. 20.—Heat No. 4970 (0.01 per cent Chromium) at 900 C. (× 1500).

solve the structure of the metal oxide layer formed at 700 C., but it appears to consist of a very fine precipitation from a saturated ferrite. It was found to stem definitely from occasional oxide particles entrapped in crevices at the surface of the iron, the oxide passing to the metal-oxide constituent as the actual metallic surface of the specimen was reached. This condition is shown at 500 diameters in the upper left-hand corner of Fig. 18. It is interesting to observe that when the metal oxide layer is continuous, the pre-existent graphite appears to have been replaced with ferrite. Such an action is understandable if it is assumed that the metal-oxide layer is due to penetration of oxygen or iron oxide, as any remaining graphite would act to reduce the oxide to iron. Thus it would be expected that the iron would form pseudomorphs after the graphite flakes. In all cases observed, the continuous metal-oxide layer did not appear in a given area until all combined or graphitic carbon had been oxidized.

With increase in exposure temperature, the structure of the metal-oxide layer was somewhat coarser and extended deeper into the unalloyed specimen until finally a network of metal-oxide areas extended almost throughout the specimen exposed to 900 C. The structure of the metal-oxide areas formed at 900 C. in the unalloyed specimen is illustrated in Fig. 19. In this latter specimen, an alteration in the ground mass adjacent to a number of graphite flakes was also noted in the small core not occupied by metal-oxide layer. This is illustrated at 1500 diameters in Fig. 20. It appears probable that this constituent forming around the graphite flake is an intermediate stage in the formation of the metal-oxide, and would indicate that the graphite flakes do furnish avenues for the entrance of oxidizing gases. The area was evidently not carbide, as a few spheroidized carbides occurred in it and the rate of cooling was not sufficiently rapid to retain austenite.

The metal-oxide areas at these higher oxidizing temperatures occurred associated with ferrite in a roughly dendritic pattern. The metal oxide layers, as can be seen in Fig. 19, appear to contain small cracks. The possibility that these might be reprecipitated graphite was considered but discarded as some graphite would certainly be redissolved at 900 C. and sorbite or pearlite areas would occur in the metal-oxide layer. Cracking would indicate a change in volume, and it can be assumed that precipitation of a voluminous precipitate such as iron oxide during the cooling of a cast iron would produce such a volume increase.

An X-ray diffraction pattern was made of the metal-oxide layer formed on the unalloyed specimen at 800 C. An alpha iron pattern was found. This furnishes some substantiation for the opinion that the metal-oxide areas consist of saturated ferrite. The amount of the precipitate is obviously insufficient to yield a separate pattern.

At higher temperatures as well as at 700 C., the addition of 0.54 per cent chromium sharply reduced the depth of penetration of the metal-oxide layer. The maximum penetration at 700 C., for example, dropped from 0.02 in. to 0.005 in.; at 800 C. from 0.06 in. to 0.04 in.; at 900 C. from 0.14 in. to 0.04 in.; and at 1000 C. from 0.10 in. to 0.06 in. The reason why the metal-oxide network penetration figure appeared less at 1000 C. than at 900 C. is because the total thickness of the unalloyed specimen was rapidly reduced by scaling at 1000 C. Increase of chromium to 1.06 per cent eliminated the formation of the metal-oxide layer at 700 C., but at the higher temperatures some formation of the metal-oxide layer was noted. In these

1.06 per cent chromium cast irons, the metal-oxide areas were much sparser and smaller, the metal-oxide layer consisting of about 25 per cent metal-oxide and 75 per cent ferrite while in the unalloyed specimens the metal-oxide areas occupied 60 per cent or more of the layer. On increasing the chromium to 1.99 per cent all traces of metal-oxide disappeared.

SUMMARY

Curves have been developed showing the total oxidation loss of cast irons containing up to 25.18 per cent chromium at four temperature levels. The resultant figures represent simple oxidation in air. Other types of atmospheres may alter the total oxidation figures but it is felt that the information furnished by these curves will be of practical value in any installation where the atmosphere is predominantly oxidizing.

The oxidation tests showed that high-chromium cast irons containing approximately 3 per cent carbon and 2 per cent silicon were not subject to greater oxidation loss than low-carbon, lower silicon, chromium steels of comparable chromium content.

From determinations of the rate of progressive oxidation at the 800 and 900 C. levels, it was found that after an initial oxidizing period lasting from 72 to 120 hr., the rate of progressive oxidation is sharply reduced in chromium-bearing irons. It has been possible to establish the chromium content necessary to produce an adherent or oxidation-resistant scale that reduced progressive oxidation to a negligible value after this initial period. At these two temperature levels as little as 0.54 per cent chromium decreases total oxidation, but 1.06 per cent chromium at 800 C., and 1.99 per cent chromium at 900 C. were necessary to materially reduce the rate of progressive oxidation. The sharpest drop in progressive oxidation at both temperatures occurred with a chromium content of 1.99 per cent. Approximately 8.27 per cent chromium at 800 C. and approximately 17.06 per cent chromium at 900 C. were required, however, to yield a scale that would furnish practically complete oxidation resistance under the present test conditions.

Structural alterations in the chromium cast irons exposed to the four oxidizing temperatures were traced. Complete absence of deoxidation at the surface of the sandblasted specimens was found at the 700 C. level with a 6.15 per cent chromium content, at the 800 C. level with 8.27 per cent chromium, at the 900 C. level with 13.28 per cent chromium and at the 1000 C. level with 17.06 per cent chromium.

The occurrence of an abnormal constituent in the unalloyed and very low chromium irons was detected, extending inward from the oxide coating. The constituent appeared to result from a fine precipitation of an iron oxide from a saturated ferrite. It has consequently been tentatively designated as the metal-oxide constituent. The formation of the metal-oxide constituent and its degree of penetration is believed to contribute to the growth of cast iron, and to shed some light on this little-understood phenomenon. As little as 0.54 per cent chromium materially decreased the penetration of this constituent into a cast iron, and with a 1.99 per cent chromium content it was completely eliminated even on exposure to 1000 C. This observation may explain the fact that chromium inhibits growth in cast iron to a greater degree than would be expected from its carbide-stabilizing power alone.

The paper is intended merely to indicate the required chromium content to reduce oxidation to a desired level. It is normally desirable to alter the carbon and possibly the silicon content of a high-chromium cast iron to meet other requirements in a given application, but a discussion of this phase must be reserved for a later paper. The oxidation results have been shown however, to be relatively independent of changes in carbon content and consequently generally applicable to all high carbon-chromium irons.

Acknowledgment:

The generous aid furnished by the Staff of the Union Carbide and Carbon Research Laboratories, Inc., in carrying out this investigation is gratefully acknowledged. In particular, the assistance of R. H. Dunlap and A. E. Shrubsall in carrying out the experimental work and of W. Crafts in reading the manuscript is appreciated. The encouragement of J. H. Critchett, Vice-President, and A. B. Kinzel, Chief Metallurgist, was of material aid in the prosecution of the work.

DISCUSSION

MR. L. A. MEKLER.[1]—Since in general, in the oil industry, a material of the type described would be used for heater hardware such as tube supports, hangers, etc., I should like to know whether data covering physical properties, particularly at high temperatures, are available on the cast material. I also notice that oxidation tests were being carried out at 700, 800, 900 and 1000 C. Would the lower chromium materials be recommended for this service to support any load? If they are too weak, I wonder of what practical value the oxidation resistance of this material at these temperatures would be?

Would they be usable in the same range of temperatures and under the same conditions as some of the low-nickel irons containing say two or three per cent of nickel? Would they be applicable within the same temperature range and the same stresses?

Would they be used with or without a stabilizing agent like molybdenum?

I am dwelling on this in some detail mainly because at the present time furnace hardware is made usually from the 25 per cent chromium, 12 per cent nickel alloy. No other grades that can be relied upon have been submitted commercially. All kinds of cheaper irons are being proposed, but when we try to use them for service at a temperature of above 1200 F., and even at 1200 F., the sections become so thick that sometimes we can afford to pay 35 cents for alloy in thin sections rather than the lower price per pound for these cast irons in thick sections. We are pleased to learn that low-chromium cast irons, which to me at least are comparatively new, could be used commercially and competitively with the more expensive alloys.

MR. J. S. VANICK.[2]—My comments will be confined entirely to the kind of cast iron found in the average gray iron foundry, in which usually the chromium content is under 2 per cent. The author points out that it is clear from the analyses of the irons, bearing in mind that this is a 3 per cent carbon, 2 per cent silicon cast iron, that the combined carbon in the base iron increases with the chromium content, so that when the chromium content reaches approximately 2 per cent, the iron is almost completely white. A study of Table I also shows that at about one per cent chromium and 1.26 combined carbon, it must have been slightly mottled, so that there is some danger in interpreting the results unless the iron is classified as mottled or white iron. But later, referring to the physical properties, the author says that "after the chromium exceeds 2 per cent, a progressive decrease in flexural properties takes place." Referring back to heat No. 4972 with combined carbon at 1.26 per cent and chromium at 1.06 per cent, I would be compelled to abandon a conviction of long standing if I agreed that the strength of a pearlitic gray iron increases as the combined carbon exceeds the eutectoid ratio, or about 0.80 per cent, because in most cast irons if the combined carbon exceeds 0.80 per cent there is very likely to be decrease in strength. The author later seems to bear that out but at a higher combined carbon level: "After the chromium exceeds 2 per cent, a progressive decrease in flexural properties takes place." I should say it ought to be somewhere under one per cent.

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[1] Combustion Engineer, Universal Oil Products Co., Chicago, Ill.

[2] Metallurgist, The International Nickel Co., Inc., Bayonne, N. J.

Finally, on comparing the oxidation of high-chromium cast irons (17 per cent chromium) as against the steel, I believe that the comparison should be confined to exactly those two high-chromium levels. I bring it up again because the author repeats in the summary this sentence: "The oxidation tests showed that high-chromium cast irons containing approximately 3 per cent carbon and 2 per cent silicon were not subject to greater oxidation loss than low-carbon, lower silicon, chromium steels of comparable chromium content." I feel sure there would be a considerable difference in oxidation resistance if the carbon varied from 2½ per cent to 3½ per cent in a low-alloy cast iron containing under 1 per cent chromium, provided it was gray iron, and contained graphite which provided access to the interior to facilitate oxidation.

These comments of mine concern details and should not detract from Mr. Burgess' paper, which is an excellent description of his work.

MR. C. O. BURGESS[3] (*author's closure*). In response to Mr. Mekler's discussion, it has been established by MacPherran[4] and Donaldson[5] that cast irons containing as little as 0.50 per cent chromium exhibit definitely higher strength than unalloyed iron at temperatures up to 600 C. (1110 F.). Naturally, low-chromium cast irons can be used in the same ranges of temperature and stress as 2 to 3 per cent nickel cast irons. The inclusion of molybdenum is more or less optional. Its presence should improve the high-temperature strength to some degree.

All low-alloy or plain cast irons lose a large share of their strength at temperatures above 600 C. Oxidation tests at higher temperatures on the low-chromium cast iron series are justified, however, from a practical standpoint, as numerous cast iron articles are now used at temperatures in the range of 700 to 900 C., when they are adequately supported or are not under excessive load. Such uses include annealing boxes, furnace parts, stove parts, grates, etc. Frequently one face alone of the casting may be exposed to such temperatures.

With higher chromium contents the temperature range in which an iron retains its strength is appreciably extended. A 17.5 per cent chromium cast iron showed a strength of approximately 20,000 psi. in a short-time tension test at 850 C. However, the high-chromium cast irons cannot be considered as competitive in fields demanding a 25 per cent chromium, 12 per cent nickel steel.

In response to Mr. Vanick's discussion on the low-chromium irons, heat No. 4972 containing 1.06 per cent chromium showed light mottling. The amount of combined carbon in a 1.00 per cent chromium cast iron can be widely varied depending on the base iron selected and the method of manufacture. In our case, the base mixture was such as to give a relatively high combined carbon and as shown in Table I the strength of the 1.06 per cent chromium iron is less that that of the 0.54 per cent chromium iron. The chromium content at which maximum strength or flexural properties are exhibited varies with the base iron. Maximum strength with a relatively hard base iron may be reached with a 0.5 per cent chromium content while with a soft base iron it may be necessary to increase the chromium to 1.0 per cent or slightly above for maximum strength.

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[3] Research Metallurgist, Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y.

[4] R. S. MacPherran and R. H. Kluger, "Effects on Cast Iron of Prolonged Heating at 800–1100 F.," *Transactions* Am. Foundrymen's Assn., Vol. 38, p. 826 (1930).

[5] J. W. Donaldson, "Influence of Chromium in Cast Iron," *Foundry Trade Journal*, June 27, 1929, p. 489.

I agree with Mr. Vanick that the observation "high-chromium cast irons containing approximately 3 per cent carbon and 2 per cent silicon were not subject to greater oxidation loss than low-carbon, lower silicon chromium steels of comparable chromium content" has been established only for high-chromium, that is, graphite-free irons. With low-chromium cast irons, that is, with under 1 per cent chromium, it is probable that a variation in oxidation resistance would be observed with wide carbon variations. In view of the fact that chromium increases the oxidation resistance of the ferrite matrix, this difference should be less marked in chromium-bearing irons than in chromium-free cast irons.

THE ALLOY CASTING RESEARCH INSTITUTE TEST BLOCK FOR HEAT-RESISTING ALLOYS; ITS HISTORY, SELECTION AND UTILIZATION[1]

BY O. E. HARDER[2]

SYNOPSIS

An earlier survey conducted by Battelle Memorial Institute to determine the opinion of foundries and testing laboratories regarding the most suitable type of test specimens for use with heat-resisting alloys in determining high-temperature tensile properties and creep characteristics is reviewed. Some experiments on the use of a pot type of casting are reported.

Further work at Battelle developed a wedge-shaped test block with a riser along the entire length but gated only at the bottom. The A.C.R.I. technical committee suggested modifying this block so as to introduce hot metal into the head or riser. The A.C.R.I. then proceeded to an evaluation of various kinds of test blocks, including end-headed round, A.S.T.M. B-4 block, keel block, star-gate, U-bar, side-head block and the block mentioned above. These various blocks were compared with reference to ease of casting, soundness of specimens, mechanical properties of specimens, and the relative amount of metal to be melted to produce a given number of test specimens.

The wedge-shaped block which would produce four tension test specimens was adopted on the basis of these requirements. This paper describes its utilization in testing three types of heat-resisting alloys which are usually designated as NC-4, CN-36 and NC-2, or 35 Ni-15 Cr, 25 Cr-12 Ni, 60 Ni-12 Cr.

In making test bars for short-time tension and creep tests on heat-resisting alloys, metallurgists have approached in different ways, the problem of selection of a test block from which the specimens may be taken. The brass foundryman tends to use a cast-to-size bar with risers at each end, or the Webbert type bar, with a fin gate leading into a feeding head over the length of the bar. The steel foundryman tends to use the regular keel block that he uses for steel.

Actual heat-resisting alloy castings usually have their main sections relatively flat and thin. These alloys generally freeze with a coarse primary grain structure, each apparent grain actually comprising a cluster of dendrites or grains. In a cast-to-size round bar, the crystals grow in radially toward the axis. In a flat casting there is a central plane at which the crystals meet as they grow in from the mold walls, the crystal arrangement being more or less symmetrical about the plane. In a keel block bar the crystals grow in from three sides. The steel foundryman is not disturbed by this lack of symmetry, since in heat treatment the cast structure is broken up and recrystallization occurs as the steel is heated above the upper critical temperature and as it cools from the gamma to the alpha field in annealing or normalizing. No such recrystallization occurs in the austenitic heat-resisting alloys. It is doubtful whether the austenitic grain size or arrangement has much effect on the room-temperature or short-time high-temperature tension tests of heat-resistant alloys.

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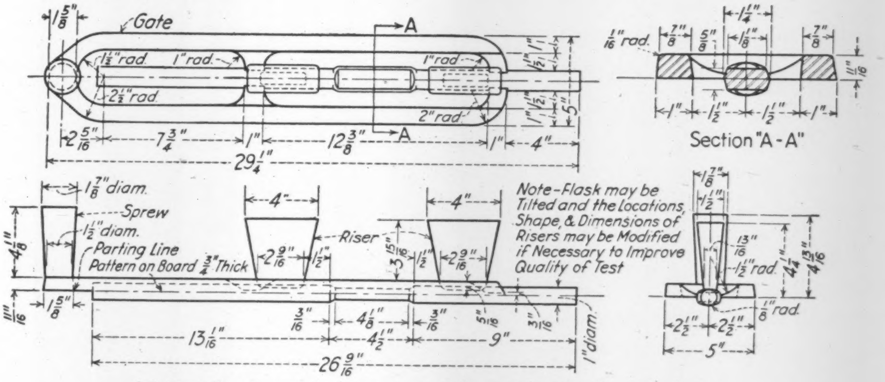
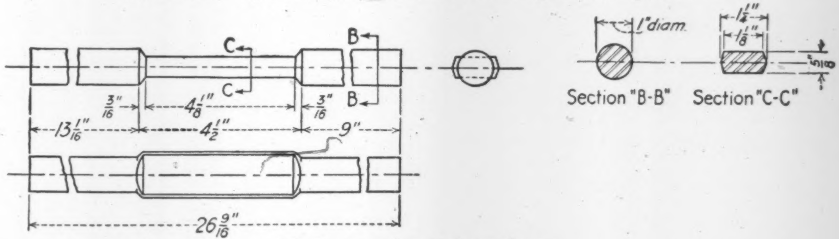
[1] A communication from Battelle Memorial Institute for the Alloy Casting Research Institute, Inc., made at the request of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys.

[2] Assistant Director, Battelle Memorial Institute, Columbus, Ohio.

in the appendix to the A.S.T.M. Tentative Method of Test for Short-Time High-Temperature Tension Tests of Metallic Materials (E 21 – 37 T),[3] shown in Fig. 1. This was arrived at after considerable discussion and experiment by three foundries whose results showed that sound castings could be obtained from this pattern. This type of test bar was not adopted till 1937, and it is still only a "tentative" standard.


Gate
1 1/2" rad.
1" rad.
2 1/2" rad.
1" rad.
2" rad.
A
A
1 5/8"
2 5/16"
7 3/4"
1"
12 3/8"
1"
4"
29 1/4"
5"
1/16" rad.
Section "A - A"
1 7/8" diam.
Sprew
1 1/2" diam.
Parting Line
Pattern on Board 3/4" Thick
Riser
Note-Flask may be Tilted and the Locations, Shape, & Dimensions of Risers may be Modified if Necessary to Improve Quality of Test
4 1/8"
1 5/8"
13 1/16"
4 1/8"
4 1/2"
9"
26 9/16"
1" diam.
2 9/16"
1/2"
1 1/2" rad.
1/8" rad.
2 1/2"
5"

(a) Details of pattern arrangement for casting tension specimen.


C
C
B
B
3/16"
4 1/8"
3/16"
13 1/16"
4 1/2"
9"
26 9/16"
1" diam.
1 1/4"
1 1/8"
5/8"
Section "B-B"
Section "C-C"

(b) Cast tension test specimen.

FIG. 1.—A.S.T.M. Committee B-4 Test Block.

However, the desire to make the grain clusters show orientation in the test bar analogous to that which is common in castings, has influenced the design of some test bar castings. This, together with a desire to make the test bar grips sufficiently long to extend outside the furnace in high-temperature testing, evidently influenced the Society's Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys in the selection of the test bar specified

On the other hand, the Joint Research Committee of the A.S.T.M. and A.S.M.E. on Effect of Temperature on the Properties of Metals, had previously selected, for its study of cast and wrought 18 per cent chromium, 8 per cent nickel alloy from split heats,[4] the multiple keel block shown in Fig. 2. This was selected after much discussion and consultation with skilled foundrymen.

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[3] *Proceedings*, Vol. 37, Part I, p. 1290 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 1654.

[4] H. C. Cross, "High-Temperature Tensile, Creep and Fatigue of Cast and Wrought High- and Low-Carbon 18 Cr 8 Ni Steel from Split Heats," Progress Report to Joint Committee, *Transactions*, Am. Soc. Mechanical Engrs., Vol. 56, July, 1934, pp. 533–553.

In work at Battelle Memorial Institute several years ago, it was necessary to make up specimens of heat-resisting alloys for high-temperature tension and creep testing. Committee B-4's test bar was then only in process of discussion. The multiple keel block bar used in the 18:8 tests froze so slowly that the grain size was huge. Either of these bars required a very high total weight of metal per test bar produced. This may not be too serious in production of standard alloys where the gates and risers may be remelted, but in experimental work on new alloys where the compositions may not be such that the risers form satisfactory melting stock for other heats, the high raw material cost of heat-resistant alloys raises a problem that is serious. Inquiry was therefore made of a score of foundries and laboratories having experience in handling these alloys as to their preference in test blocks. The majority preferred some form of keel block bar, with keel about 2½-in. deep of which only the lower inch was used to provide the actual specimen. The length of the keels and the number attached to one head varied considerably, from a single short keel to designs like Fig. 2.

The Webbert bar had been used, but in general, attempts to cast bars to size, or with a reduced breaking section, were stated to be unsatisfactory. Some producers have cast a large flat plate, for example, 20 by 20 by 1 in., and cut the test specimens from the plate. It is understood that radiographic examination of such plates showed a large proportion that were unsound.

Aside from a few opinions maintaining that specimens should be cut from actual castings so as to take in the question of insufficient feeding, it was generally agreed that ample feeding, analogous to that in a keel block bar, was required, to evaluate alloys. Beyond that, the recommendations were widely variant, though several metallurgists expressed a fear that in the feeding of the Committee B-4 bar, the metal flow might be such that two streams would meet in the filling of the breaking section of the specimen. It was quite evident that the B-4 bar did not have sufficiently unanimous acceptance to render it impossible to consider other types. Indeed, as one man expressed it, there seemed to be as many ideas on the subject as there were foundry superintendents.

Vertical Keels:

One suggestion, made to Battelle by H. C. T. Han, then of the Illinois Steel Co., was to use a feeding head like that of a keel block with a vertical keel instead of the usual horizontal keel. The keel suggested is 24 in. long, 1 in. thick, 8 in. high, the feeder head 24 in. long by 4 in. wide by 3 in. high. The fin keel is horn gated on one end. The feeder head carries a 5 in. high riser on the other end. The specimens are cut vertically.

Another suggestion from N. L. Mochel of Westinghouse was to cast a tall cylindrical pot, thickened at the top into a heavy feeding head and provided with a horn gate to introduce the metal at the bottom of the casting. The pot is 10 in. outside diameter, 8¼ in. inside diameter, 10 in. high surmounted by a 10-in. diameter head of any desired height. The test specimens are cut out as vertical strips from the bottom of the pot. Good results were said to have been obtained with this on heat-resisting alloys. The use of such a casting for a direct comparison of ordinary and centrifugal castings, was suggested. Neither the

Han scheme nor the pot conveniently allowed a long enough bar to form integral grips, but experience with high-temperature creep and tension testing had convinced the Battelle workers that integral grips were not essential.

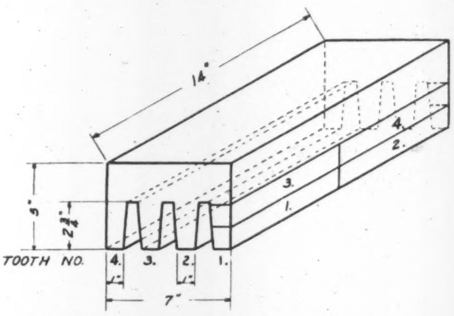
14"
5"
2¾"
TOOTH NO.
4.
3.
2.
1.
7"
1"
1.
2.
3.
4.

FIG. 2.—Multiple Keel Test Block of the Joint Research Committee, of A.S.T.M. and A.S.M.E., on the Effect of Temperature on the Properties of Metals.

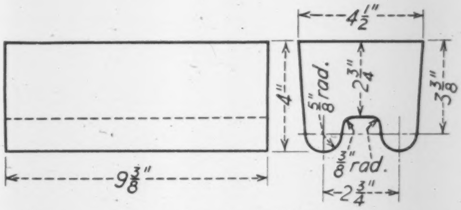
4½"
4"
9⅜"
5/8" rad.
2¾"
3⅜"
3/8" rad.
2¾"

FIG. 3.—Keel Block Test Bar Coupon Casting.

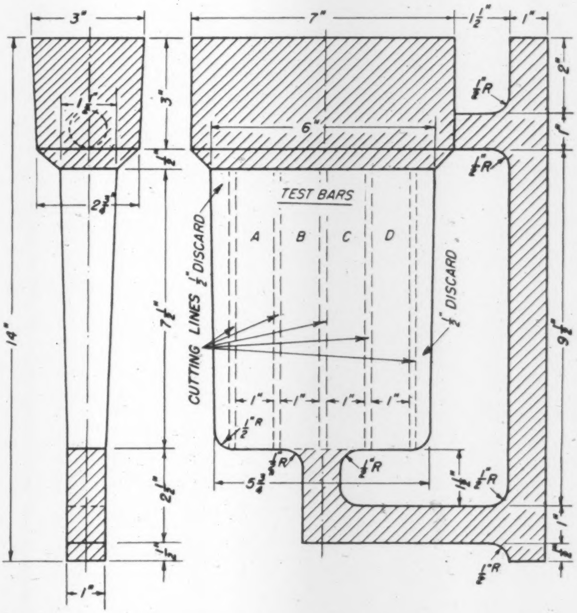
3"
7"
1½"
1"
2"
3"
1½"
½"R
6"
1"
½"R
2¾"
TEST BARS
A
B
C
D
½" DISCARD
CUTTING LINES
½" DISCARD
14"
7½"
9½"
1"
1"
1"
1"
½"R
⅜"R
½"R
5¾"
1¼"
½"R
2¼"
1"
½"
1"
½"R
1"

FIG. 4.—Battelle-A.C.R.I. Test Block for Heat-Resisting Alloys.

The cylindrical pot scheme was tried out at Battelle since it promised to provide the greatest number of specimens for a given weight of metal, but on the particular heat-resisting alloys it was desired to study, which had somewhat unusual compositions and high shrinkage, it was found difficult to cast these free from defects. Tapering of the section wall seemed necessary, with a thicker section at the top. The making of dry sand molds with the large central core and the horn gate was a bit complicated. While the pot could doubtless be redesigned so as to be entirely satisfactory, and has the advantage that every vertical strip freezes at the same rate as any other, it seemed simpler to turn to a modification of the idea of taking specimens vertically.

Hence the upright specimen idea suggested by Han was developed at Battelle along the lines of Fig. 4, save that it was, at first, gated from the bottom only. Specimens cut from the vertical block were radiographed and found sound, and their properties seemed satisfactorily uniform.

Therefore, this type of block, modified so as to supply hot metal to the shrink head through a second gate instead of through the test block itself, was considered, along with others, by the Alloy Casting Research Institute, for the production of test specimens of various heat-resisting alloys.

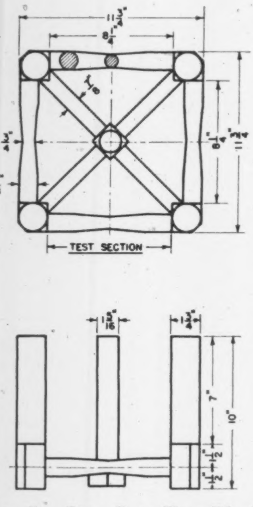

FIG. 5.—Star Gate Test Block.

Several types of specimens, some of which had been used by different foundries for routine control, were considered. Due to the lack of comparable data on the results obtained from the different bars, two foundries agreed to make comparisons, using a 35 per cent nickel, 15 per cent chromium alloy. All bars, save two defective ones from the B-4 bar, were X-rayed and found to be radiographically sound, whatever the type of bar.

One foundry compared a modified keel block for steel (Fig. 3), the B-4 bar (Fig. 1), and an end-headed 1-in. diameter round bar with heads at each end, fed through one of the heads (Fig. 7). Castings were tested in the as-cast condition only. The alloy contained 0.53 per cent carbon, 1.21 per cent manganese, 0.99 per cent silicon, 15.3 per cent chromium and 36.5 per cent nickel. The average room temperature tensile results were:

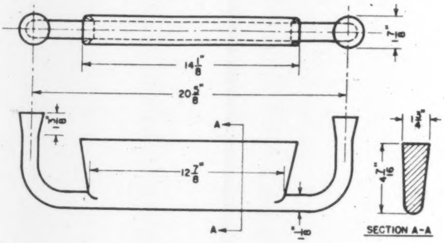

FIG. 6.—Side Head Test Block.

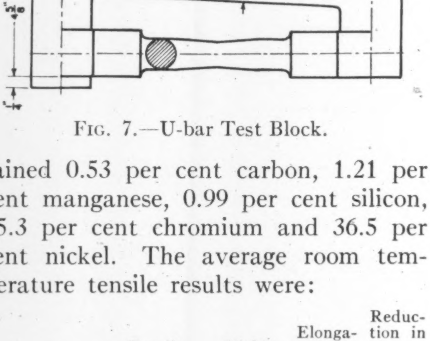

FIG. 7.—U-bar Test Block.

	Tensile Strength, psi.	Yield Strength, psi.	Elongation, per cent	Reduction in Area, per cent
U-bar (Fig. 7)	65 100	33 800	4.9	5.0
B-4 bar (Fig. 1)[a]	74 300	40 300	6.3	5.8
Keel block (Fig. 3)	67 800	34 600	6.0	6.0

---

[a] Two specimens were defective and were not radiographed or tested.

The other foundry used an alloy of 0.51 per cent carbon, 0.66 per cent manganese, 1.03 per cent silicon, 15.9 per cent chromium, 36.9 per cent nickel with the following results, as-cast:

	Tensile Strength, psi.	Yield Strength, psi.	Elongation in 2 in., per cent	Reduction in Area, per cent
Star gate (Fig. 5)	70 300	36 000	8.0	9.6
U-bar (Fig. 7)	70 200	41 000	7.5	8.8
B-4 bar (Fig. 1)	62 300	37 600	4.5	6.3
Block of Fig. 4	62 900	37 800	5.0	4.8
Side head (Fig. 6)	64 600	32 300	6.0	6.0
Keel block (Fig. 3)	63 200	36 000	5.5	5.5

A further comparison was made on castings that had been held at 1600 F. for 48 hr., with the following results:

	Tensile Strength, psi.	Yield Strength, psi.	Elongation in 2 in., per cent	Reduction in Area, per cent
Star gate (Fig. 5)	80 350	37 000	4.3	4.8
U-bar (Fig. 7)	72 900	38 700	3.0	4.3
B-4 bar (Fig. 1)	64 100	40 000	2.3	2.8
Block of Fig. 4	70 500	39 100	3.3	3.5
Side head (Fig. 6)	74 900	38 500	4.0	3.8
Keel block (Fig. 3)	74 400	38 600	4.5	4.8

The gross weight of metal required by each of these types to produce stock for four test bars was found to be:

Type of Test Block Casting	Metal Required for Four Test Specimens, lb.	
	Reported	Calculated from Drawings
Star gate	33	47
U-bar	40	48
B-4 bar	140	105
Block of Fig. 4	35 to 40	41
Side head	60	66[a]
Keel block	128[b]	53[c]

[a] Assuming two specimens from each casting.

[b] Reported weight for four specimens from casting of Fig. 3.

[c] Calculated for keel block of Fig. 2 assuming two specimens from each keel.

On the basis of freedom from defects, proper feeding, reasonable weight, and similarity of grain size to commercial castings, the block of Fig. 4 was adopted in the fall of 1937 for the cooperative investigations of the A.C.R.I.

Subsequent experience with a large number of bars from the block of Fig. 4, made by several producers, has indicated it to be satisfactory for a variety of heat-resisting alloy compositions. Some of the evidence for this statement is summarized below.

One cannot assume that any one method of producing test bars will serve for all alloys, even within the broad designation of heat-resisting alloys; hence the method has been considered tentative and subject to improvement if and when accumulating data should indicate changes to be necessary. The available data have therefore been continually studied, not only from the point of view of evaluation of the alloys and the variables involved in their manufacture, but also from that of the suitability of the test block.

The properties of the alloys and the effects of the variables are another story and one not yet complete. Data cited below are therefore to be taken merely as representing certain lots of metal and certain variables rather than as representing average or desired properties and not as representing specification values, since variables have been intentionally juggled for investigative purposes. Such data, however, serve excellently for indicating the degree of utility of the test block.

In Fig. 4, it will be noted that the edge strips are discarded but that the inner strips *B* and *C* will freeze somewhat more slowly than strips *A* and *D*. Comparison of average properties of *B* and *C* with those of *A* and *D* was made on a total of 103 specimens from 9 heats of NC-4 alloy (35 per cent nickel, 15 per cent chromium). Tension tests were made at room temperature for material as cast and after aging at 1600 F., and short-time tension tests were also made at 1800 F.

The differences in average properties as related to position in the block, taking the grand average of strips *A*, *B*, *C*, and *D* as the base line, were as shown in Table I. In such a comparison, one

TABLE I.—DIFFERENCES IN AVERAGES FROM GRAND AVERAGE.

35 per cent nickel, 15 per cent chromium.

	As Cast		Aged		1800 F.	
	Strips *A* and *D*	Strips *B* and *C*	Strips *A* and *D*	Strips *B* and *C*	Strips *A* and *D*	Strips *B* and *C*
Tensile strength, psi	+550	−550	+2250	−2250	+25	−25
Yield strength (0.2 per cent set), psi	−200	+200	+150	−150	0	0
Yield strength (0.1 per cent set), psi	−100	+100	+50	−50	+25	−25
Proportional limit, psi	0	0	−50	+50	+50	−50
Elongation in 2 in., per cent	+0.25	−0.25	+0.5	−0.5	+1.00	−1.00^a
Reduction in area, per cent	−0.10	+0.10	+0.35	−0.35	−1.75	+1.75^a

[a] These variations from the grand averages were under 5 per cent.

TABLE II.—DIFFERENCE IN AVERAGES FROM GRAND AVERAGE.

60 per cent nickel, 12 per cent chromium.

	As Cast		Aged		1800 F.	
	Strips *A* and *D*	Strips *B* and *C*	Strips *A* and *D*	Strips *B* and *C*	Strips *A* and *D*	Strips *B* and *C*
Tensile strength, psi	+2000	−2000	−400	+400	−125	+125
Yield strength (0.2 per cent set), psi	+100	−100	0	.....	−75	+75
Yield strength (0.1 per cent set), psi	+600	−600	0	0	+200	−200
Proportional limit, psi	+125	−125	+250	−250	+75	−75
Elongation in 2 in., per cent	+0.25	−0.25	0	0	+1.25	−1.25^a
Reduction in area, per cent	+0.30	−0.30	+0.25	−0.25	+3.25	−3.25^a

[a] These variations from the grand averages were under 4 per cent and 7 per cent for elongation and reduction in area respectively.

TABLE III.—DIFFERENCE IN AVERAGES FROM GRAND AVERAGE.

25 per cent chromium, 12 per cent nickel.

	As Cast		Aged		1800 F.	
	Strips *A* and *D*	Strips *B* and *C*	Strips *A* and *D*	Strips *B* and *C*	Strips *A* and *D*	Strips *B* and C
Tensile strength, psi	+3600	−3600	+3400	−3400	+200	−200
Yield strength (0.2 per cent set), psi	+450	−450	+350	−350	+200	−200
Yield strength (0.1 per cent set), psi	+350	−350	+100	−100	+150	−150
Proportional limit, psi	−250	+250	−100	+100	+200	−200
Elongation in 2 in., per cent	+2.1^a	−2.1^a	+0.5	−0.5	+1.25	−1.25
Reduction in area, per cent	+0.9^a	−0.9^a	+0.4	−0.4	−1.3	+1.3

[a] These variations from the grand averages were under 15 per cent and 5 per cent for the elongations and reductions in area, respectively.

TABLE IV.—DIFFERENCE IN AVERAGES FROM GRAND AVERAGE.

25 per cent chromium, 12 per cent nickel—three heats of closely similar composition.

	As Cast		Aged		1800 F.	
	Strips *A* and *D*	Strips *B* and *C*	Strips *A* and *D*	Strips *B* and *C*	Strips *A* and *D*	Strips *B* and *C*
Tensile strength, psi	+1300	−1300	+2000	−2000	+150	−150
Yield strength (0.2 per cent set), psi	+400	−400	+100	−100	+400	−400
Yield strength (0.1 per cent set), psi	+200	−200	−200	+200	+125	−125
Proportional limit, psi	−500	+500	−300	+300	+275	−275
Elongation in 2 in., per cent	+0.5	−0.5	+0.5	−0.5	+1.25	−1.25^a
Reduction in area, per cent	0	0	+0.5	−0.5	−1.1	+1.1^a

[a] These variations from the grand averages were under 4 per cent.

notes not only the magnitude of the variation but its sign. It is obvious that the properties of the inner specimens *B* and *C* were indistinguishable from those of the outer specimens *A* and *D*.

Similar comparisons on 6 heats and some 60 specimens of NC-2 (60 per cent nickel, 12 per cent chromium) gave the data for Table II.

There is a slight tendency for better properties in the outer specimens, but the figures for bars from either position would be considered acceptable checks, except perhaps for tensile strength as cast, and one might expect that, were as many data available as for Table I, the differences would diminish.

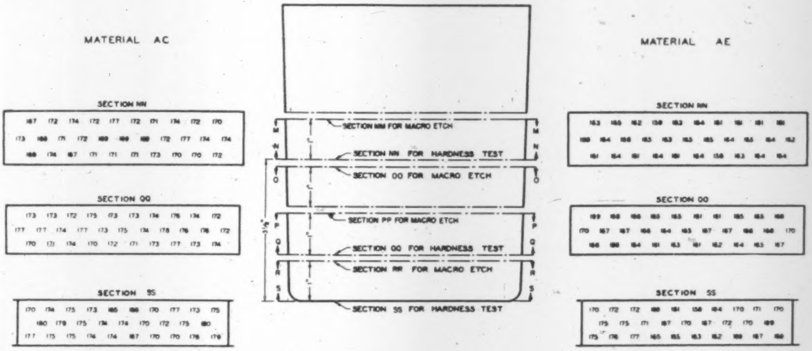
MATERIAL AC
SECTION NN
SECTION OO
SECTION SS
SECTION MM FOR MACRO ETCH
SECTION NN FOR HARDNESS TEST
SECTION OO FOR MACRO ETCH
SECTION PP FOR MACRO ETCH
SECTION QQ FOR HARDNESS TEST
SECTION RR FOR MACRO ETCH
SECTION SS FOR HARDNESS TEST
M
N
O
P
Q
R
S
3¼"
MATERIAL AE
SECTION NN
SECTION OO
SECTION SS

FIG. 8.—Hardness Survey of CN-36 Alloy.

Brinell hardness numbers taken at ½-in. intervals and shown in respective locations of tested sections.

Similar calculations on 6 heats, approximately 100 test bars, of CN-36 (25 per cent chromium, 12 per cent nickel) type alloy gave the data contained in Table III.

The rather general tendency for better properties in the outer specimens (*A* and *D*) and especially the rather large differences shown in the case of the tensile strength and ductility values of the as cast material and the tensile strength values of the aged material are too large to neglect. It is to be noted that the deviations are practically negligible in the case of the proportional limit and yield strength values, that is, in tests where no large deformation is involved. The negligible difference shown for the tensile strength values at 1800 F. is also of interest.

Preliminary study of the data indicated that the marked variation might be connected with certain intended variations in chemical compositions in three of the heats.

Separate calculations were then made for three of the heats in which this variable was present in an amount such as thought not to influence the properties, with the results shown in Table IV.

The relatively good agreement between the values for outside and inside bars as shown in Table IV indicated the variations noted in Table III were not necessarily due entirely to the characteristics of the test block.

Thus, an explanation for the effect of position may be further sought among the heats containing the suspected composition variable, to see whether or not this variable plays any part in imparting the positional differences.

Spare test blocks of a heat of CN-36 alloy (material "AC") which showed a rather marked difference between the tensile strength and ductility of the outer and inner bars and another heat of CN-36 alloy (material "AE") showing a rather good uniformity for bars from either position were sectioned as shown in Fig. 8.[5]

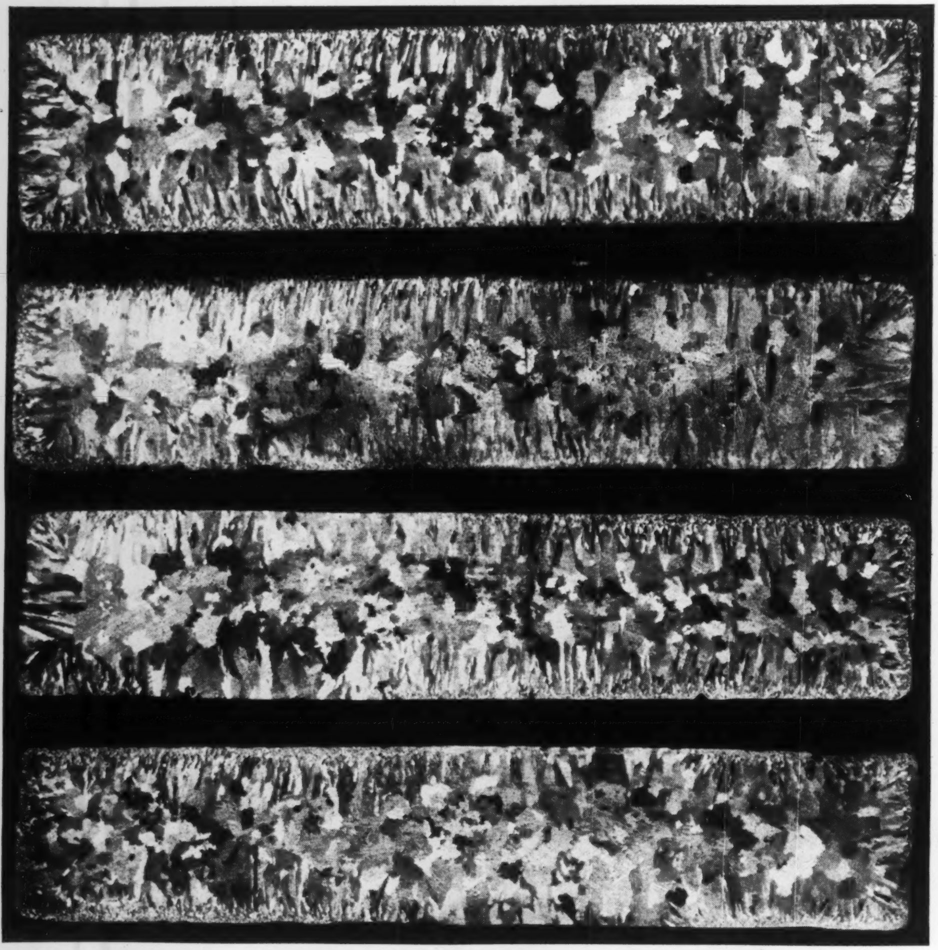

FIG. 9.—Macrosections of CN-36 Alloy Material "AC" (25 per cent Chromium, 12 per cent Nickel).

Off chemical composition in regard to one chemical element.
Tapping temperature—3100 F.
Pouring temperature—2600–2500 F.

Considering the end discards, and the locations of the breaking section of specimens from locations *A*, *B*, *C* and *D* of Fig. 4, it appears that the material actually tested, represented by sections *NN*, *QQ*, and *SS* of Fig. 8 are a trifle more uniform in hardness in material "AE" than in material "AC."

The etched sections of the two materials show that in both cases the material actually tested (breaking section of test bars) is in the equiaxed crystal area. The only apparent difference is that a little porosity or sponginess is present in sections *PP* and *OO* of material "AC." It will be noted from the legends of Figs. 9 and 10 that material "AC" was not only off composition but that it was tapped at a much higher temperature than "AE." Whether this combination of compositional effect and high temperature, or some other variable, is responsible, it seems that the slight porosity at the inside locations is probably responsible for the variations in properties of outside and inside bars, especially since the room temperature tests show that both strength and ductility are higher at the sounder locations *A* and *D*. The possibility of a trace of porosity in the portion last to cool may be a drawback in this test block as compared with test blocks of lighter section (Fig. 5 for example) but it may be suggested that some commercial castings have sections as large as those in the test block of Fig. 4.

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[5] Reference should be made to Fig. 4 for the portions of the block discarded and those used for test specimens.

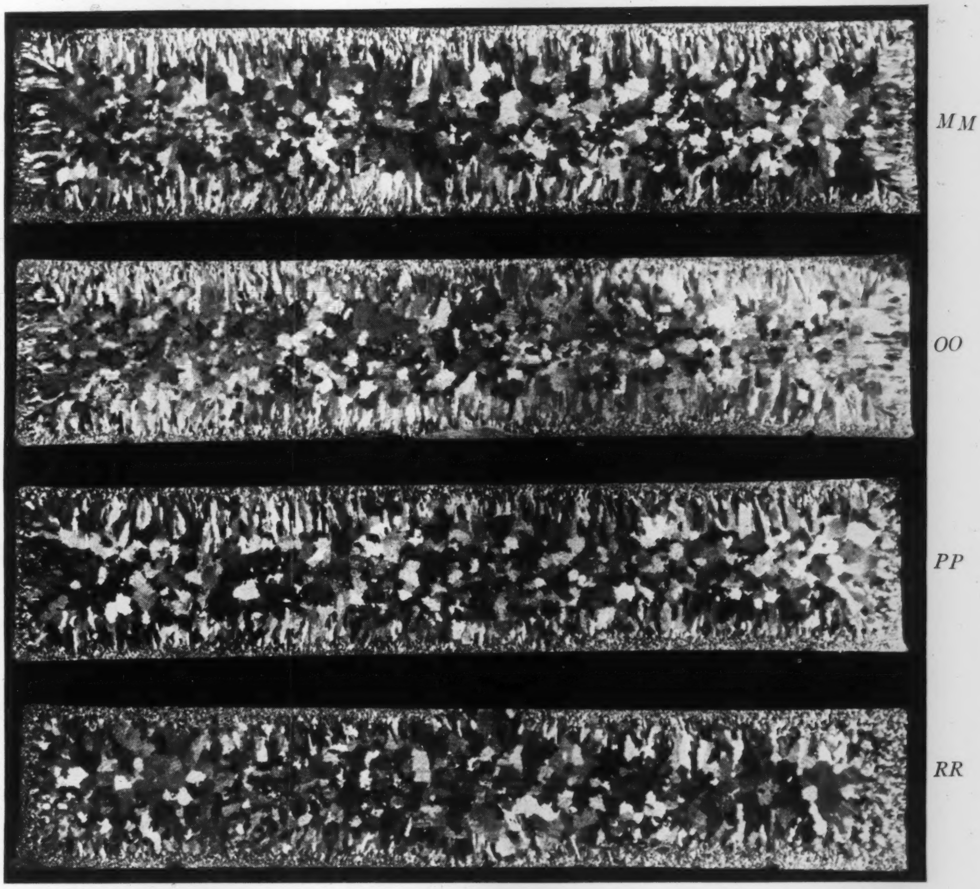

FIG. 10.—Macrosections of CN-36 Alloy Material "AE" (25 per cent Chromium, 12 per cent Nickel).

Normal in chemical composition for materials in Table IV.
Tapping temperature—2660 F.
Pouring temperature—2650–2580 F.

The hardness survey and the etched structure raise the question whether it is really necessary to discard the outer strips. Perhaps still better reproducibility might be had by using the outer (now discarded) strips rather than *B* and *C*, but using the sections now discarded might introduce some differences in crystal orientation. At any rate, the *A* and *D* locations, even in material "AC," give very satisfactory uniformity. On the whole, among many lots of several different types of heat-resisting alloys, including some variants of those above mentioned, the test block bars returned consistent results, in the hands of many different foundrymen using somewhat varying melting practices.

Further evidence of reasonable consistency of results is found in creep tests of a CN-36 alloy at temperatures of 1600 to 1800 F. using inside (*B* or *C*) and outside (*A* or *D*) bars from test blocks of a heat which showed a rather large difference in the room temperature tensile strength and ductility of the outer and inner bars. When the creep data were plotted on the usual log-log graphs for stress *versus* rate of deformation, there was good agreement for the points for inside and outside bars for the tests both at 1600 and 1800 F.

It is also noted that the deviations in short-time tests (Table III) tend to be smallest in proportional limit and yield strength values, that is, where no large deformation is involved; also, a rather good uniformity of tensile properties is shown for the outer and inner bars in short-time tests at 1800 F.

On the whole, the A.C.R.I. test block appears to be serving its purpose of supplying a good ratio of test bars to weight of metal cast and of giving results consistent enough to serve in the evaluation of variables in composition and in processing. No claim is made that it is necessarily suitable for all heat-resistant alloys nor that it is the last word in suitability for the alloys studied. However, its use has provided such consistent data on like alloys, prepared in many foundries, that one is encouraged to think that, in the study of a given variable, the number of duplicate sources from which material must be taken before conclusions can be drawn from the results, may be cut down in comparison with the use of test blocks that are more "temperamental" in the hands of different operators.

Acknowledgment:

The author is indebted to the Board of Directors of Alloy Casting Research Institute and to Clyde E. Williams, Director of Battelle Memorial Institute, for permission to publish this paper. He is also indebted to the cooperating members of the A.C.R.I. and especially to Earnshaw Cook, who was chairman of the High-Temperature Committee during the time most of this research was conducted and who had an important part in the early work to select a standard cast block; to Fred Grotts, former chairman, and F.B. Foley, present chairman of the technical committee of A.C.R.I. and to L. E. Welch, present chairman of the High-Temperature Committee.

The author is glad to acknowledge the valuable work of the following members of the Battelle staff: H. W. Gillett, James T. Gow, D. A. Roberts and Howard C. Cross.

RÉSUMÉ OF ROUND-TABLE DISCUSSION ON EFFECT OF SUB-ATMOSPHERIC TEMPERATURES ON THE PROPERTIES OF METALS

Prepared by F. B. Foley[1]

A Round-Table Discussion on Effect of Sub-Atmospheric Temperatures on the Properties of Metals, sponsored by the Joint Committee, of A.S.M.E. and A.S.T.M., on Effect of Temperature on the Properties of Metals, was held on Tuesday, June 27, 1939, in connection with the annual meeting of the A.S.T.M. at Atlantic City, N. J.

Open discussion of the general subject followed the presentation of two prepared papers:

"Factors Affecting Notched-Bar Impact Tests on Steel at Low Temperatures," by Walter Crafts and John J. Egan[2]

"Sub-Size Charpy Relationships at Sub-Zero Temperatures," by H. Habart and W. J. Herge[3]

In opening the meeting, N. L. Mochel, Chairman of the Joint Committee, pointed out that, although most of the work of the committee had to do with the effect of elevated temperatures on metals, its functions included, as its title indicated, the effect of temperatures broadly—effects of sub-atmospheric as well as elevated temperatures. He called attention to the many applications of metals requiring service under stresses at low temperatures and the need for greater availability of data concerning the behavior of metals under such conditions. The committee has a Subcommittee 13, under the chairmanship of Mr. Foley, which had organized the present session, principally for the purpose of bringing out some of the known facts bearing on the subject and as a stimulus to the proposed gathering of all available information in a form which, while it might not prove as extensive as the data which have made up the "Creep Data" book compiled by the Joint Committee, would serve the purpose in the low-temperature field that the "Creep Data" book is serving in the elevated-temperature field. Following these remarks the meeting was turned over to Mr. Foley who presided and opened the general discussion, following the presentation of the two previously mentioned formal papers, with a presentation of some data which were pieced together to give a general picture of the effect of sub-atmospheric temperatures on the notched-bar impact values of ferrous metals.

The type of specimen used in his work was always the conventional keyhole notched Charpy specimen, 1 cm. square, the notch being 5 mm. deep. Table I gives results obtained with a variety of ferrous alloys, plain carbon steel, low-alloy steel and high nickel-iron alloys.

The values in Table I were obtained on specimens taken from treated 1-in. sections. Simple annealing and annealing-and-drawing treatments were used as a rule to minimize to some extent the effect of the elements in

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[1] Superintendent of Research, The Midvale Co., Nicetown, Philadelphia, Pa.

[2] See p. 659.

[3] See p. 649.

TABLE I.

Composition, per cent								Condition	Charpy Impact, ft-lb.			
Carbon	Manganese	Silicon	Nickel	Chromium	Copper	Molybdenum	Vanadium		Room Temperature	−2 F.	−85 F.	−300 F.
0.32	0.44	0.23	....	....	....	....	....	Annealed Annealed and drawn	20.45 23.88	8.99 7.05	3.75 2.95	0.48 0.48
0.20	0.85	0.15	....	....	....	....	....	Annealed Annealed and drawn	35.83 41.40	24.70 32.28	0.68 2.14	0.68 0.48
0.24	0.47	0.20	....	0.78	....	0.39	....	Annealed Annealed and drawn	45.10 48.55	32.28 36.95	1.50 1.08	0.88 0.68
0.26	0.42	0.22	....	0.79	....	....	0.25	Annealed Annealed and drawn	51.16 57.80	46.85 43.89	24.27 14.32	0.88 0.88
0.16	1.13	0.15	....	....	....	....	....	Annealed Annealed and drawn	52.90 53.83	49.47 47.29	1.71 26.37	0.48 1.08
0.12	1.13	0.20	....	....	....	....	0.21	Annealed Annealed and drawn	59.16 63.26	63.27 58.29	37.18 45.99	2.41 0.88
0.10	0.45	0.19	3.41	....	....	....	....	Annealed Annealed and drawn	56.96 55.15	43.47 58.71	35.29 48.55	1.09 1,09
0.12	1.02	0.17	3.77	....	....	....	....	Annealed Annealed and drawn Quenched and drawn	32.66 49.03 52.47	17.98 38.57 40.21	8.89 24.56 43.17	1.73 1.94 3.02
0.12	0.48	0.17	3.25	....	....	....	0.19	Annealed Annealed and drawn	54.67 62.80	55.56 58.57	48.13 57.35	1.29 2.58
0.14	0.49	0.18	1.10	....	2.22	....	....	Annealed Annealed and drawn	60.48 62.23	53.35 59.17	44.31 46.42	1.10 1.30
0.12	0.45	0.18	3.58	....	....	0.27	....	Annealed Annealed and drawn	44.73 49.42	44.31 51.16	36.35 39.78	14.73 2.14
0.12	1.09	0.12	3.39	....	....	0.28	....	Annealed Annealed and drawn Quenched and drawn	36.57 56.02 59.62	25.04 54.24 59.12	5.12 28.51 46.18	1.29 2.58 3.71
0.10	0.34	0.15	5.13	....	....	....	....	Annealed Annealed and drawn	38.15 41.39	28.52 38.15	21.27 26.37	1.71 2.81
0.16	1.80	0.28	50.4	....	....	....	....	1800 F. water	81.24	58.27	87.07	75.90
0.27	1.64	0.28	58.8	....	....	....	....	2050 F. water	54.22	....	....	43.06

TABLE II.

Composition, per cent						Size	Treatment	Charpy Impact, ft-lb.			
Carbon	Manganese	Silicon	Nickel	Chromium	Molybdenum			Room Temperature	−75 F.	−150 F.	−300 F.
0.27	1.64	0.28	59.8	0.15	....	4 in. square	As forged 1700 F. air-quenched 2050 F. water-quenched	57.8 49.0 47.3	....	....	54.2 54.2 61.3
0.24	0.42	0.40	9.50	18.5	....	2 in. square	As forged 1750 F. air-quenched 2050 F. water-quenched	21.1 26.7 56.0	....	....	28.9 10.0 47.3
0.11	0.35	0.10	3.25	0.08	0.25	1 in. plate Rings	{1600-air 1400-air 1200-furnace}	49.0 37.4	.... 42.2 .... 31.9	.... 37.8 .... 23.8	....
0.14	0.33	0.63	9.30	18.6	....	1 by 6-in. Casting	As cast 1900 F. water-quenched	....	....	35.5 23.7	....
0.15	0.25	0.11	3.22	0.15	0.27	1 by 6-in. Casting	{Normalized Air-quenched Draw}	....	....	27.0 31.3 29.6 28.9	....
0.08	0.26	0.09	3.35	0.10	0.25	1 by 6-in. Casting	{Normalized Air-quenched Draw}	....	....	29.6 25.3 22.5	....

retarding transformations and thus to permit applying the relative values to pieces of larger dimensions without too much disparity. There appears to be some reason for drawing the conclusion that some elements appear to act as "specifics," to use a medical term, for low-temperature service. This appears to be true in pearlitic steels of manganese, nickel, copper and vanadium up to limited percentages. On the other hand, carbon and silicon appear to be contraindicated. Whether this be true or whether it is the effect of elements on the resultant metallographic structure is a debatable question. Certainly structure is a factor of great importance since it is possible with plain low-carbon steel to obtain high values, even at liquid air temperature, if the piece be small enough to undergo thorough quenching and then be completely drawn. Added elements may then owe their beneficial effect to their influence on the structure, or perhaps the effect is the result of the combined influence, directly as a specific and indirectly in creating a proper metallic structure.

Austenitic steels are generally well known to maintain a high degree of toughness at low temperatures. This is shown by the results obtained from the examples of 50 to 59 per cent nickel which have notched-impact values at liquid air temperature as high as or higher than pearlitic steels have at atmospheric temperature.

Sizeable forgings of the low-carbon-nickel-molybdenum steel have been produced commercially having Charpy impact values at −150 F. of over 15 ft-lb. Not only can good values be obtained with forgings of this type of ferritic steel, but practically as good values are found in the same composition of castings as well. Some test results from larger sizes of forgings and castings are given in the accompanying Table II.

In general, it was Mr. Foley's opinion that the production of good toughness at sub-atmospheric temperature, as indicated by the notched-bar impact test, depends largely on homogeneity of the metal with respect to both structure and freedom from internal stresses. Tensile properties at low temperatures hold little practical interest since in no case have they been found to be adversely affected by refrigeration—invariably being higher than at room temperature.

H. K. Huester, in discussing the problem from the point of view of metals for aircraft, cited values obtained at −80 C. (−176 F.) at the National Bureau of Standards. The tensile strengths and yield points of S.A.E. steels and of 18 per cent chromium, 8 per cent nickel alloy were found to be higher at −80 C. (−176 F.) than at room temperature. S.A.E. 4130 steel, with a tensile strength of 280,000 psi., had 10 ft-lb. Charpy value at −80 C. (−176 F.). Engine mount bolts of S.A.E. 2330 steel, with a tensile strength of 150,000 psi. had 30 ft-lb. impact value at the same temperature. Aircraft engineers would like to have tough steels, at temperatures encountered by aircraft, with a tensile strength of 250,000 to 300,000 psi. With 180,000 psi. tensile strength the impact value of S.A.E. 4340 steel fell from 40 ft-lb. at room temperature to 25 ft-lb. at −80 C. (−176 F.) and "Two-Score" with 16 per cent chromium, 1 per cent nickel and a tensile strength of 220,000 psi. had a value of 23 ft-lb. at room temperature and but 12 ft-lb. at −80 C. (−176 F.).

Results of sub-atmospheric tests of copper and copper-base alloys were presented by Smith[4] of the American Brass Co. This subject was covered quite completely in the 1931 Symposium[5] and the results presented by Mr. Smith serve to bring it up to date. Few words are required to sum up the data which show that commercial wrought-copper alloys have greater toughness and higher strength when refrigerated than at room temperature, and castings are nearly as good.

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[4] Cyril Stanley Smith, "Mechanical Properties of Copper and Its Alloys at Low Temperatures: a Review," see p. 642.

[5] Symposium on Effect of Temperature on the Properties of Metals, published jointly by the American Society for Testing Materials and The American Society of Mechanical Engineers (1931). (Available as a separate publication.)

Nickel and nickel-base alloys were discussed by B. B. Morton of the International Nickel Co. As in the case of copper and its alloys, nickel and its alloys suffer no deterioration either in strength or toughness as a result of exposure to sub-atmospheric temperatures. Mr. Morton's results were obtained on a 45-deg. V-notch Charpy specimen. Table III gives values for "Inconel" (80 per cent nickel, 13 per cent chromium, 7 per cent iron, carbon, etc.), monel metal (69 per cent nickel, 29 per cent copper) and pure nickel.

TABLE III.—IMPACT VALUES OF "INCONEL," MONEL, AND NICKEL AT SUB-ZERO TEMPERATURES.

Data from Research Laboratory, The International Nickel Co., Inc.

Material	Treatment	Charpy Impact, (ft-lb.) 45-deg., V-notch		
		Room Temperature	−112 F.	−310 F.
"Inconel" (80%, Ni, 13% Cr, 75% Fe, carbon, etc.)	Hot-rolled	236	206	187
	Cold-drawn-center	33[a]	34[a]	28[a]
	Cold-drawn-outside	40[a]	38[a]	33[a]
	Annealed at 1600 F.	128	126	112[a]
Monel (69% Ni, 29% Cu)	Hot-rolled	219	213	196
	Cold-drawn-center	161	143	131[a]
	Cold-drawn-outside	135	129	122
	Annealed at 1400 F.	215	219	207
Nickel	Hot-rolled	135	236	227
	Cold-drawn-center	185	205	210
	Cold-drawn-outside	190	236	208
	Annealed at 1400 F.	216	236	234

[a] Specimen completely fractured. All other values are for specimens that had broken only partially.

Mr. Morton called attention to the fact that only in the case of cold-drawn metal did complete fracture ever occur in the tests. The tensile strength of 70,000 to 85,000 psi. and yield strength of 30,000 to 40,000 psi. of monel metal undergo an increase of 40 to 60 per cent at very low temperatures, and the same is true of nickel and "Inconel," their properties being of the same order as those of monel. All of these metals lend themselves readily to welding without loss of physical properties in the weld metal or the parent metal as a result of refrigeration.

While the non-ferrous metals copper and nickel suffer no ill effects due to refrigeration, Mr. Foley observed that there still remain many fields of service where ferrous metals, even though they do vary in their response to the influence of low-temperature exposure, have to be used. With this observation the meeting was opened for general discussion, which concerned almost exclusively the adaptability of ferrous metals to use at sub-zero temperatures.

V. T. Malcolm observed that double normalized 3.25 per cent nickel, 0.25 per cent molybdenum steel gave a value of 30 ft-lb. at −150 F. and had been used to replace 18 per cent chromium, 8 per cent nickel in some instances. Valves for helium plants of 65 per cent copper, 10 per cent tin, 15 per cent lead are still in place after 7 to 9 yr. of service. V. N. Krivobok called attention to the fact that details of fabrication had not been presented in connection with results obtained and that the temperature of finish forging and rolling often has a profound influence on the impact values subsequently obtained after heat treating. A. V. de Forest suggested that Charpy values on notched specimens were useless unless applied to structures having notches. The way to overcome notch brittleness is to do away with the notch, and engineers must constantly visualize notch effects. It was remarked by Mr. Foley that it is not always the intentional notch that causes failure, but it is the inadvertent notch that must be assumed to be present. Sufficiently sharp notches will cause fatigue failure at any temperature.

M. S. Northup stated that petroleum plants are being operated successfully at −150 F. after proper study of low-temperature effects. Practical applications are going ahead without waiting upon theoretical analysis of causes of brittleness, impact testing being used broadly as a criterion of quality. G. F. Jenks made a plea for more detailed information concerning failures, their origin and cause. Most failures, he observed, were due to minor defects and these minor defects must be found in order to make progress.

H. J. French summarized low-temperature effects in an extended discussion. Strength was not the criterion. To carry the case to extremes, of two metals both having 100,000 psi. tensile strength—one having zero elongation, zero reduction and zero impact value and the other 25 per cent elongation, 50 per cent reduction of area and 100 ft-lb. impact value—surely the former is very dangerous and the latter quite safe. Impact resistance is an item of confidence. The nickel-chromium austenitic stainless steels have high low-temperature impact values but are relatively expensive. Ferritic steels, on the other hand, are cheaper but they may or may not retain their toughness. He listed five influential factors affecting the low-temperature toughness of ferritic steels: (*a*) low carbon content, (*b*) deoxidation practice used in melting, (*c*) alloy content, (*d*) structural refinement and homogeneity and (*e*) internal stresses. If under (*a*) the carbon content is high a heat treatment, not always a practical one, is necessary. Under (*b*) he observed that deoxidation with silicon and manganese is less desirable than killing with aluminum because of grain size effect. Under (*c*) carbon content has to be balanced with proper alloy content. Of two low-alloy steels, one with carbon 0.10 per cent, the other with carbon 0.23 per cent, the lower carbon steel can be fabricated readily and even be overheated in normalizing without seriously lowering the impact values at room temperature and at −50 F. Under the same conditions, but with carbon 0.23 per cent, overheated areas may give satisfactory values at room temperature but, when cooled to −50 F., the steel may show only a fraction of the impact value developed in the fine-grained condition. By proceeding with the given factors, under proper consideration, ferritic steels can be produced having values of over 15 ft-lb. up to 40 ft-lb. at temperatures as low as −150 to −200 F. Mr. Foley stated that he was not so sure that a fine McQuaid-Ehn grain size was essential to good low-temperature impact resistance. He had determined the McQuaid-Ehn grain size of a nickel-molybdenum steel which gave excellent values at −150 F. and had found it to be coarse. It was his opinion that the grain size conferred by heat treatment, which was quite small in the case cited, was the true criterion and not that developed in the standard McQuaid-Ehn test. He was therefore not convinced that aluminum deoxidation was essential.

H. C. Cross stated that the grain size effect could be studied by using steels in possession of the Joint Committee, which were available as a result of work done on the effect of grain size on elevated temperature properties.

There was an opinion that it was as much the form and distribution of the ferrite and pearlite as it was the grain size which determined the resistance to notched-bar embrittlement at sub-atmospheric temperatures, but the facts of the matter remain to be proven.

MECHANICAL PROPERTIES OF COPPER AND ITS ALLOYS AT LOW TEMPERATURES: A REVIEW

By Cyril Stanley Smith[1]

In 1931 Russell (**1**)[2] contributed to the A.S.T.M.-A.S.M.E. Symposium on Effect of Temperature on the Properties of Metals a complete discussion of all but the earliest literature relating to the properties of metals at subatmospheric temperatures. The following is an attempt to summarize the literature of intervening years in so far as it relates to copper and its alloys. A few data from the files of the American Brass Co. are presented for the first time.

The outstanding research of the period under discussion is that of Colbeck and MacGillivray (**2**) who describe the tensile and impact properties of a representative wide range of materials at temperatures down to that of liquid air. Their results are summarized in Table I. Krupkowski (**3**) and Broniewski and Wesolowski (**4**) studied, respectively, the properties of copper and three brasses in boiling liquid air (−180 C.) and in acetone and solid CO_2 (−78 C.). Their researches are valuable in that they show the variation of hardness, impact resistance, and tensile properties of the same materials over the whole range of temperature from −180 C. to the melting point. The low-temperature tests alone are summarized in Table II. de Haas and Hadfield (**5**) have performed tension tests on copper and a cast bronze at the temperature of liquid hydrogen (Table III), the lowest temperature at which tests have been performed. Pester (**6**) determined the strength of cold-drawn copper wires of various diameters at temperatures down to −60 C. (Table IV). In addition to the tension test results shown in Tables V and VI, Pester (**7**) and Kuroda (**8**) have given stress-strain curves for hot-rolled and annealed copper, respectively, at various low temperatures.[3] Tests on brass made by Smirnov and Chernjak (**10**) are available only as an abstract which gives the results shown in Table VII, with no details of the heat treatment of the samples or method of testing.

Hitherto unpublished figures for the tensile properties of a silicon bronze (Everdur) at low temperatures are given in Table VIII. Table IX shows the impact properties of deoxidized copper and five copper alloys.

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[1] Research Metallurgist, The American Brass Co., Waterbury, Conn.

[2] The boldface numbers in parentheses refer to reports and papers appearing in the list of references appended to this paper, see p. 648.

[3] It is significant that neither of these shows the "yield point" extension of copper that Schoenmaker (**9**) reported at low temperatures. Kuroda's extensometer is somewhat crude but Pester's would undoubtedly detect any discontinuity in the elongation curve if it occurred. de Haas and Hadfield report a value for the "drop-of-beam" yield point for copper at low temperatures but, since they also report a value of 26,900 psi. for annealed copper at room temperatures, their values cannot be taken seriously. Colbeck and MacGillivray note "not observed" for the drop-of-beam yield point of annealed copper at all temperatures. The Polish investigators give "elastic limits" determined from low-magnification Amsler recorder curves but make no comment on discontinuous behavior of any materials. On the whole the evidence seems to be against the existence of a yield point extension without stress increase in copper at any temperature. Further work is desirable on this point. Annealed brass generally does show a definite yield point with a small decrease of stress even at room temperature.

TABLE I.—TENSILE PROPERTIES OF COPPER ALLOYS

Colbeck and MacGillivray (**2**) 1933.

Material	Property[a]	Tests on 0.25-in. Diameter Specimens						Tests on 0.504-in. Diameter Specimens	
		Room Temp.	−10C. (14F.)	−40C. (−40F.)	−80C. (−112F.)	−120C. (−184F.)	−180C. (−292F.)	Room Temp.	−180C. (−292F.)
Copper	TS	31 400	32 000	33 800	38 500	41 200	58 000	33 100	51 200
99.985% Cu	YP	8 600	8 900	9 200	10 100	10 800	11 500	^{c}	^{c}
(Annealed)	El	48	40	47	47	45	58	53	67
	RA	76	78	77	74	70	77	75	75
	Izod	43	—	45	44	45	50	—	—
Cupro Nickel	TS	51 500	56 200	59 600	61 600	66 000	73 700	59 000	81 400
79.71% Cu	YP	27 700	28 700	29 000	28 900	29 200	32 500	45 200	48 500
20.58% Ni	El	26	28	29	29	28	36	35	44
(Annealed)	RA	78	77	77	76	75	72	72	71
	Izod	77	—	81	79	84	85	—	—
Cupro Nickel	TS	60 000	66 100	67 600	72 200	77 100	89 700	65 700	88 200
54.36% Cu	YP	19 600	18 400	21 000	22 100	24 100	26 300	44 200	53 800
45.78% Ni	El	40	47	43	48	48	57	39	60
(Annealed)	RA	77	78	78	75	74	76	72	74
	Izod	81	—	85	81	83	86	—	—
Copper Nickel	TS	70 800	77 500	80 000	85 300	91 700	112 700	66 500	98 200
28.86% Cu	YP	20 900	25 500	24 900	27 100	28 600	29 600	28 600	38 000
69.58% Ni	El	41	48	47	40	41	51	48	59
(Annealed)	RA	75	77	76	74	74	72	71	69
	Izod	90	—	93	90	93	97	—	—
Brass 70-30	TS	51 100	53 100	54 700	57 100	61 200	73 500	54 100	73 500
69.56% Cu	YP	28 200	28 600	26 900	27 300	28 000	29 600	36 500	43 000
30.50% Zn	El	49	49	58	60	55	75	58	81
(Annealed)	RA	77	77	77	79	78	73	75	74
	Izod	66	—	66	69	71	79	—	—
Nickel Silver	TS	75 300	76 200	78 200	83 100	89 800	104 200	74 400	102 200
55.15% Cu	YP	27 900	27 800	28 600	27 500	28 800	28 400	32 300	45 100
30.50% Ni	El	33	32	34	39	38	41	43	48
14.30% Zn	RA	53	50	52	52	52	55	58	58
(Annealed)	Izod	80	—	87	83	80	87	—	—
Manganese Bronze	TS	72 400	70 300	75 500	75 500	80 900	94 800	71 700	96 200
56.45% Cu 1.25% Pb	YP	24 000	22 500	27 000	27 000	27 800	28 800	35 000	^{c}
38.85% Zn 1.08% Fe	El	28	33	29	31	35	37	36	35
1.43% Mn 0.90% Sn	RA	44	41	45	43	45	41	41	31
(Annealed)	Izod	20^b	—	21^b	22^b	21^b	21^b	—	—
Aluminum Bronze	TS	77 200	77 000	78 900	82 600	88 000	96 000	77 600	78 300
91.1% Cu 1.02% Zn	YP	26 600	26 800	26 900	27 100	27 600	29 200	39 000	^{c}
0.44% Mn 7.31% Al	El	26	33	35	31	32	29	33	32
(Annealed)	RA	29	30	36	30	31	30	34	28
	Izod	24^b	—	24^b	24^b	21^b	21^b	—	—
Cu-Ni-Al Alloy	TS	51 500	49 500	55 800	57 400	61 600	67 200	—	—
92.3% Cu	YP	11 400	13 600	16 100	16 300	15 000	22 900		
5.86% Ni	El	42	40	41	43	44	49		
1.73% Al	RA	80	80	80	79	82	82		
(Quenched from 900 C.)	Izod	58	—	—	—	—	67		
Cu-Ni-Al Alloy	TS	91 000	100 100	103 700	100 800	108 000	107 100	—	—
(Quenched from 900 C.; Reheated 2 hr. at 550 C.)	YP	—	54 900	61 600	51 500	63 400	54 900		
	El	24	22	25	23	26	26		
	RA	50	48	57	57	63	67		
	Izod	40^b	—	—	—	—	55		
Copper Beryllium	TS	186 600	189 500	188 800	201 600	197 800	214 400	—	—
2.56% Be	YP	125 400	126 600	118 500	147 400	138 900	155 000		
(Quenched from 800 C.; Reheated 2 hr. at 300 C.)	El	2.6	0.8	0.4	0.4	0.4	3.0		
	RA	5.0	9	5	5	4	6		
	Izod	2^b	—	3^b	3^b	3^b	3^b		
Copper Beryllium	TS	76 200	—	—	86 700	—	111 600	—	—
2.56 Be	YP	24 900	—	—	29 100	—	50 000		
(Quenched from 800 C.)	El	36	—	—	38	—	41		
	RA	50	—	—	54	—	57		
	Izod	41	—	—	40	—	40		

[a] TS = Tensile Strength, psi. Specimens machined from 1-in diameter commercial rods.
YP = Yield Strength, 0.1 per cent offset. On large samples by drop of beam. Single test.
El = Elongation in 2 in., per cent.
RA = Reduction of area at fracture, per cent.
Izod = Impact resistance, ft-lb., Izod specimens.

[b] Specimen broken, all others unfractured.

[c] Yield point not observed.

TABLE II.—PROPERTIES OF COPPER AND BRASS AT LOW TEMPERATURES.
Krupkowski (**3**)—1931.
Broniewski and Wesolowski (**4**)—1933.

Material	Temperature of Test		Yield Point (Amsler Recorder), psi.	Tensile Strength, psi.	Elongation in 50 mm., per cent	Uniform Elongation, per cent	Reduction of Area, per cent	Impact Resistance kg-m. per sq. cm. (10 by 8 by 100 mm. Specimen, 45-deg. Sharp V Notch)	Cone Hardness, kg. per sq. mm. (120-deg. Cone 25 kg. 5 min.)
	deg. Cent.	deg. Fahr.							
Electrolytic copper, annealed 1 hr., 700 C.	20	68	5 500	34 300	50.5	44.0	71.4	10.0	48
	−78	−110	14 200	41 600	50.0	40.8	73.6	9.5	62
	−183	−295	12 400	52 000	50.5	41.9	83.3	9.1	84
Electrolytic copper, commercial cold worked	20	68	53 400	58 700	8.4	0.0	51.5	6.6	112
	−78	−110	58 100	60 500	12.0	0.0	56.6	8.0	127
	−183	−295	59 700	64 800	11.2	0.0	61.2	7.4	152
Brass, 33% Zn annealed 2 hr. 550 C.	23	73	39 300	57 000	50.4	41.7	72.0	14.4	77
	−78	−110	43 700	61 200	49.8	40.7	76.6	16.9	86
	−183	−295	57 200	76 400	50.8	44.5	70.7	14.1	100
Brass, 33% Zn cold worked 40% reduction	23	73	84 600	85 400	6.3	0.5	66.5	8.1	142
	−78	−110	91 800	92 500	7.8	0.0	71.5	9.2	149
	−183	−295	101 700	102 900	10.1	1.6	66.5	9.4	172
Brass, 40% Zn annealed 2 hr. 550 C.	20	68	19 900	57 600	51.3	40.6	75.5	8.6	95
	−78	−110	22 500	61 200	53.0	41.5	74.6	8.6	104
	−183	−295	28 500	75 800	55.3	44.2	71.0	8.3	142
Brass, 40% Zn cold worked 25% reduction	21	70	56 900	79 700	19.8	9.8	65.5	5.1	160
	−78	−110	59 900	83 000	21.0	11.1	67.7	5.3	160
	−183	−295	80 100	98 400	24.4	14.5	64.1	5.3	181
Leaded brass, 40% Zn, 1.3% Pb annealed 2 hr. 550 C.	20	68	20 600	52 800	50.2	41.3	62.5	4.4	...
	−78	−110	24 600	54 600	49.8	42.4	64.0	4.9	...
	−183	−295	28 900	69 000	50.6	44.0	62.1	4.6	...
Leaded brass, 40% Zn, 1.3% Pb cold worked 12% reduction	22	72	45 800	63 800	28.2	21.0	57.0	2.2	...
	−78	−110	54 100	70 400	27.0	20.8	59.0	2.5	...
	−183	−295	69 900	86 600	30.8	22.9	57.0	2.2	...

Tests on Copper by Krupkowski using 4.5-mm. diameter specimens.

Tests on Brass by Broniewski and Wesolowski using test specimen 5 mm. in diameter. A few apparent misprints have been corrected.

TABLE III.—TENSION TESTS IN LIQUID HYDROGEN (−253 C.).
de Haas and Hadfield (**5**)—1933.

Material	Temperature of Test		Yield Point (drop-of-beam), psi.	Tensile Strength, psi.	Elongation, per cent (30-mm. gage length, 3-mm. diam.)	Reduction of Area, per cent
	deg. Cent.	deg. Fahr.				
Electrolytic Copper						
99.7% Cu	Room Temperature		26 900 (!)	38 800	37.5	77.0
Quenched from 750 C.	−253	−423	30 700	44 100	60.0	75.0
Phosphor Bronze						
10.0% Sn, 1.61% Zn, 88.38% Cu	Room Temperature		29 400	45 500	30.0	36.0
As cast	−253	−423	46 400	58 000	18.0	38.5

The reported yield and tensile strength figures of annealed copper at room temperatures are much higher than would normally be expected.

Discussion of Results:

Little comment is needed on any of these results. In practically every case the yield strength and tensile strength of wrought copper alloys increase as the temperature drops, and the ductility increases, sometimes considerably. The increase in ductility is generally greater in the range −120 to −180 C. than between room temperature and −120 C. It is to be noted that while the elongation increases, the reduction of area changes little and sometimes shows a small decrease; this is a result of greater uniform extension before necking down commences. Colbeck and MacGillivray report tests on different diameter specimens which do not always agree in the effect of temperature. The greatest difference is in the case of aluminum bronze and manganese bronze which when tested as 0.5-in. diameter specimens in liquid air decrease in both elongation and reduction of area but if they are tested as 0.25-in. diameter specimens an increase in both ductility figures occurs.

TABLE IV.—TENSILE PROPERTIES OF DRAWN COPPER WIRE.
Pester (6)—1930.

Material[a]	Temperature of Test		Tensile Strength, psi.	Elongation, per cent (200-mm. gage length)	Reduction of Area, per cent
	deg. Cent.	deg. Fahr.			
Copper, 2.1-mm. diam.	20	68	66 800	1.1	57
	0	32	69 100	1.8	56
	−20	−4	69 600	1.2	56
	−30	−22	70 400	1.9	54
	−60	−76	72 000	2.0	58
Copper, 2.8-mm. diam.	20	68	62 600	2.0	56
	0	32	64 100	2.5	57
	−20	−4	65 400	2.5	58
	−30	−22	65 800	2.8	58
	−60	−76	68 400	3.5	56
Copper, 3.6-mm. diam.	20	68	58 700	2.0	57
	0	32	59 900	2.1	57
	−20	−4	61 300	2.0	57
	−30	−22	62 200	3.0	57
	−60	−76	64 100	4.0	57
"Bronze," 2.1-mm. diam.	20	68	90 100	1.6	70
	0	32	92 500	1.7	71
	−20	−4	94 000	1.7	69
	−30	−22	95 000	1.9	72
	−60	−76	98 400	2.0	71
"Bronze," 2.8-mm. diam.	20	68	85 300	1.9	70
	0	32	86 600	1.8	70
	−20	−4	88 000	1.9	69
	−30	−22	88 400	2.1	72
	−60	−76	90 800	2.0	70

[a] Copper wire was drawn from hot-rolled rod 6.35 mm. in diameter to size tested without annealing. Bronze wire drawn from hot-rolled rod 10 mm. in diameter. In all cases specimens were held 24 hr. at temperature before testing. Data are read from curves as no tabular results are given. A later paper (7) gives the composition of bronze as 99.5 per cent copper, 0.5 per cent magnesium.

TABLE VI.—TESTS ON ANNEALED COPPER.
Kuroda (8)—1932.

Material	Temperature of Test		Tensile Strength, psi.	Elongation, per cent (20-mm. gage length, 3 by 5-mm. section)	Elongation, per cent (150-mm. gage length, 5-mm. diam.)
	deg. Cent.	deg. Fahr.			
Copper Sheet 3 mm. thick, quenched from 800 C.	16	61	32 000	35	..
	−60	−75	35 500	37	..
	−80	−112	37 700	37	..
	−120	−185	39 800	37	..
	−180	−292	45 500	36	..
Copper Wire 5-mm. diam. annealed	25	77	34 100	..	37
	−60	−75	37 000	..	32
	−120	−185	40 500	..	30
	−180	−292	45 900	..	31

TABLE V.—TENSION TESTS ON HOT-ROLLED COPPER.
Pester (7)—1932.

Material	Temperature of Test		Yield Strength, 0.2 per cent Offset, psi.	Tensile Strength, psi.	Elongation, per cent (100-mm. gage length, 20-mm. diam.)	Reduction of Area, per cent
	deg. Cent.	deg. Fahr.				
Electrolytic Copper 99.96 to 99.98% Cu hot rolled to 40 mm. square	20	68	7100	31 300	55	70
	−20	−4	7100	33 800	56.2	70
	−60	−76	7800	36 400	57.3	67
	−77	−107	7100	37 600	57.2	68
Copper 99.5%, Mg 0.5% hot rolled to 40-mm. square	20	68	8500	36 300	57.2	81
	−20	−4	8400	38 600	61.5	80
	−60	−76	8800	40 100	60.8	78
	−77	−107	9900	42 900	62.5	81

These values are read from curves as no tabular results are given in the paper.

TABLE VII.—TESTS OF SMIRNOV AND CHERNJAK (**10**)—1936.

Material	Temperature		Tensile Strength, psi.	Elongation, per cent	Reduction of Area, per cent	Impact Resistance, kg-m. per sq. cm.	Brinell Hardness
	deg. Cent.	deg. Fahr.					
Brass: 58.9% Cu 38.7% Zn 1.5% Pb	20 −183	68 −297	60 400 82 500	25.7 36	47 32.4	5.95 5.32	94 124
Brass: 57.14% Cu 40.75% Zn 0.69% Pb 0.90% Fe trace Mn	20 −183	68 −297	51 900 72 300	22.3 26.9	19.9 19.2	5.23 5.18	94 113

TABLE VIII.—TENSILE PROPERTIES OF EVERDUR AT LOW TEMPERATURES.

Tests made in 1932 at the National Bureau of Standards for the American Brass Co. Materials contained 2.75 per cent silicon, 0.97 per cent manganese, 0.15 per cent iron, balance copper. Commercial rod annealed at 0.656 in. and cold drawn to 0.5 in., the final size. Amsler machine. Speed of loading about 20,000 psi. per min.

Temperature of Test		Tensile Strength, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent
deg. Cent.	deg. Fahr.			
25	77	74 150[a]	39.8[a]	75.1[a]
0	32	76 200	31.2	70.4
−80	−112	82 900	31.7	72.4
−190	−310	100 500	36.2	72.5

[a] Tests on rod 0.5 in. in diameter. All other tests on specimens turned to 0.25 in. in diameter. Average of 2 tests.

TABLE X.—FATIGUE TESTS ON BRASS AT LOW TEMPERATURES.

Boone and Wishart (**12**)—(1935).

Temperature		Endurance Limit, psi., 50×10^6 cycles	
deg. Cent.	deg. Fahr.	Unnotched	45-deg. Sharp Notch
27	80	26 000	17 000
−12	10	....	17 500
−29	−20	27 500	16 500
−40	−40	27 000	17 500

Krause machine. 0.25 in. brass rod containing 62 per cent copper, 33 per cent zinc, 3 per cent lead. Annealed ¾ hr. at 650 F. (345 C.) and furnace cooled.

TABLE IX.—IMPACT TESTS ON SOME ANNEALED COPPER ALLOYS.

	Silicon Bronze	Tobin Bronze	Deoxidized Copper	Ambrac	30 per cent Cupro Nickel	Admiralty Brass
Copper, per cent	95.75	60.25	99.950	74.28	69.27	70.57
Zinc, per cent	....	38.91	....	5.43	0.62	28.44
Lead, per cent	....	0.01	....	....	....	0.01
Tin, per cent	....	0.75	....	....	....	0.95
Iron, per cent	0.17	0.08	....	....	....	0.03
Nickel, per cent	....	....	....	19.49	29.54	....
Silicon, per cent	3.05	....	....	....	....	....
Manganese, per cent	0.98	....	....	0.80	0.57	....
Phosphorus, per cent	....	....	0.025	....	....	....
Yield strength, psi., 0.5 per cent elongation under load	29 900	35 000	8 290	35 200	34 200	13 300
Tensile strength, psi	62 400	64 600	32 600	54 700	57 600	46 500
Elongation, per cent (2-in. gage length, 0.7-in. diam.)	65.5	41.0	57.5	43.0	53.5	83.5
Rockwell hardness	"B" 54	"B" 61	"F" 43	"B" 49	"B" 55	"F" 64
Charpy Impact Resistance ft-lb.						
−115 C. (−175 F.)	64.5	16.9	48.2	52.6	60.0	59.2
−80 C. (−110 F.)	69.2	17.9	46.3	55.8	58.7	61.5
−50 C. (−60 F.)	73.1	18.1	43.7	55.5	59.4	58.9
−30 C. (−25 F.)	74.6	18.3	44.7	56.4	59.4	60.8
−18 C. (0 F.)	80.1	17.6	43.9	61.0	60.0	58.8
3 C. (38 F.)	73.3	16.1	46.6	69.6	63.9	60.6
20 C. (70 F.)	66.4	16.1	46.8	67.5	66.3	60.8
65 C. (150 F.)	59.8	14.7	38.7	49.5	53.0	51.0
120 C. (250 F.)	55.0	13.6	36.0	47.8	52.5	47.8
205 C. (400 F.)	50.2	11.7	32.7	44.9	50.2	45.2

Tensile tests at room temperatures on specimens 0.7 in. in diameter. Impact tests made by Battelle Institute in 1936 for American Brass Co. All alloys were tested in annealed condition. Standard Charpy specimens (keyhole notch) cut from ¾-in. diameter rods. 120 ft-lb. Amsler machine used. Specimens tested in standard time of 5 sec. after removal from bath at stated temperature. Specimens at −115 C. were frozen in ether with liquid air and allowed to heat to testing temperature. All others in bath 15 min. at testing temperature. Figures are average of three tests. All Charpy specimens were unfractured except those of Tobin Bronze.

In cold-worked material the percentage improvement of strength at liquid air temperatures is about the same and the improvement of ductility is generally greater than in annealed material.

Castings show a curious difference in behavior from wrought materials. Tension tests on the cast bronze reported by de Haas and the wider range of cast materials tested by Strauss (**11**) (included in Russell's 1931 summary) always show less ductility at low temperatures than at normal ones. Both elongation and reduction of area figures show this, although the strength increases just as in wrought material. This may possibly be nothing but an effect of grain size.

TABLE XI.—HARDNESS OF ANNEALED COPPER.

Reference and Test Method	Temperature		Hardness $\left(H = \frac{P}{\pi r^2}\right)$, kg. per sq. mm.
	deg. Cent.	deg. Fahr.	
Engel and Katz (**13**), 1937 Cone penetrator, 120-deg. angle Copper (composition not stated) Annealed 1 hr. at about 1000 C.	85	185	45.7
	70	158	46.7
	55	131	47.8
	20	68	49.1
	−4	25	50.0
	−20	−4	50.8
	−35	−32	51.5
	−53	−64	52.2
	−70	−94	53.9
	−87	−125	54.5
	−108	−162	55.6
	−124	−191	57.6
	−133	−207	59.2
	−143	−225	60.2
	−191	−313	61.7
Holm and Meissner (**14**), 1932 Ball penetrator, 2.5-mm. diam. "Very pure copper," annealed	20	68	2.0 (2.5 kg.)
	−273	−459	4.0 (5 kg.)
	−273	−459	4.1 (10 kg.)

The rotating-beam tests of Pester (**7**) on wires of copper and a copper-magnesium alloy show an increased number of reversals to fracture at −60 C. compared with the behavior at 15 C. The endurance limit of annealed brass rod as determined in a Krause type machine by Boone and Wishart (**12**) (Table X) shows a trend toward a slight increase in endurance limit at −40 C. with no definite change in notch sensitivity. Impact tests on notched bars, as reported by various investigators (see Tables I, II, VII, IX), generally show either practically no change or a small increase at low temperature. No copper alloys develop impact brittleness at low temperatures and, since most Charpy specimens do not fracture, comparative figures are meaningless.

Hardness tests (Tables II, VII, XI) show a uniform and considerable increase in hardness.

Because of the supposed lack of transformation it would not be expected that cooling to low temperatures would have any effect on the subsequent properties of copper alloys at room temperature. While this is generally true, some of Colbeck and MacGillivray's results for Izod impact resistance do show a change, the greatest being for pure copper and a 20 per cent cupronickel. The Izod impact values of these two materials were increased 14 and 18 per cent, respectively, by this treatment, but the specimens remained unfractured.

Summary:

All wrought copper alloys are alike in that the effect of temperatures lower than normal is to improve all useful mechanical properties. Hardness, yield strength, and tensile strength show material improvement, and the ductility (particularly as shown by elongation) is better at the temperature of liquid air or below than at room temperatures. Impact properties are practically unaffected. The ductility of cold-worked alloys increases to a greater extent than does that of annealed material and they are, therefore, the logical materials for stressed parts for low-temperature service. Castings of copper alloys show a small decrease in ductility at low temperatures.

Acknowledgment:

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SUB-SIZE CHARPY RELATIONSHIPS AT SUB-ZERO TEMPERATURES

By H. Habart[1] and W. J. Herge[1]

Synopsis

Charpy impact tests were made on eight steels at 70 F. and sub-zero temperatures down to −150 F. Standard and various sub-size specimens were broken at each testing temperature. In general, ferritic steels lost impact resistance, as measured on standard and two-thirds size specimens, when the testing temperature was decreased. One-half size specimens also lost impact resistance, but not to the marked degree as larger size specimens. Smaller specimens have practically constant impact resistance throughout the temperature range used.

An austenitic 18 per cent chromium, 8 per cent nickel alloy had increasing impact resistance with decreasing temperature.

The results of the tests were summarized to show relationships between sub-size impact specimens and standard size specimens at each testing temperature. A table of working values for relationship between the various specimen sizes at each testing temperature is included.

Charpy impact testing is gradually becoming an important item in many industrial laboratories, because of the increasing demand for steels which have high impact resistance at sub-zero temperatures. It is generally accepted that steels for sub-zero service shall have a Charpy impact value, on standard size test specimens of either 15 or 20 ft-lb. at designated temperatures in the range between 70 F. and −150 F. It has not been a difficult problem to furnish steels which have the required impact resistance as determined on standard size test specimens. There has been, however, some concern about establishing impact values when the thickness of the materials is not enough to permit machining standard size specimens. Various relationships have been devised to provide for the sub-size specimens which must necessarily be cut from thin sections.

Sub-size Charpy impact specimens are usually made to a thickness which is a simple fraction of the standard 0.394 in. (1 cm.). Thus the cross-sectional dimensions of sub-size Charpy impact specimens commonly used are as follows:

Standard	0.394 in. by 0.394 in.
$\frac{2}{3}$ size	0.263 in. by 0.394 in.
$\frac{1}{2}$ size	0.197 in. by 0.394 in.
$\frac{1}{3}$ size	0.131 in. by 0.394 in.
$\frac{1}{4}$ size	0.098 in. by 0.394 in.

Only a limited number of steels are used to meet sub-zero impact requirements. Eight of those steels were selected for this investigation. The program was outlined to include Charpy impact testing of the eight steels at such temperatures as would be required by service conditions. All sizes of impact specimens were tested at each

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[1] Assistant Metallurgist, and Special Test Supervisor, respectively, National Tube Co., Subsidiary of United States Steel Corp., Ellwood City, Pa.

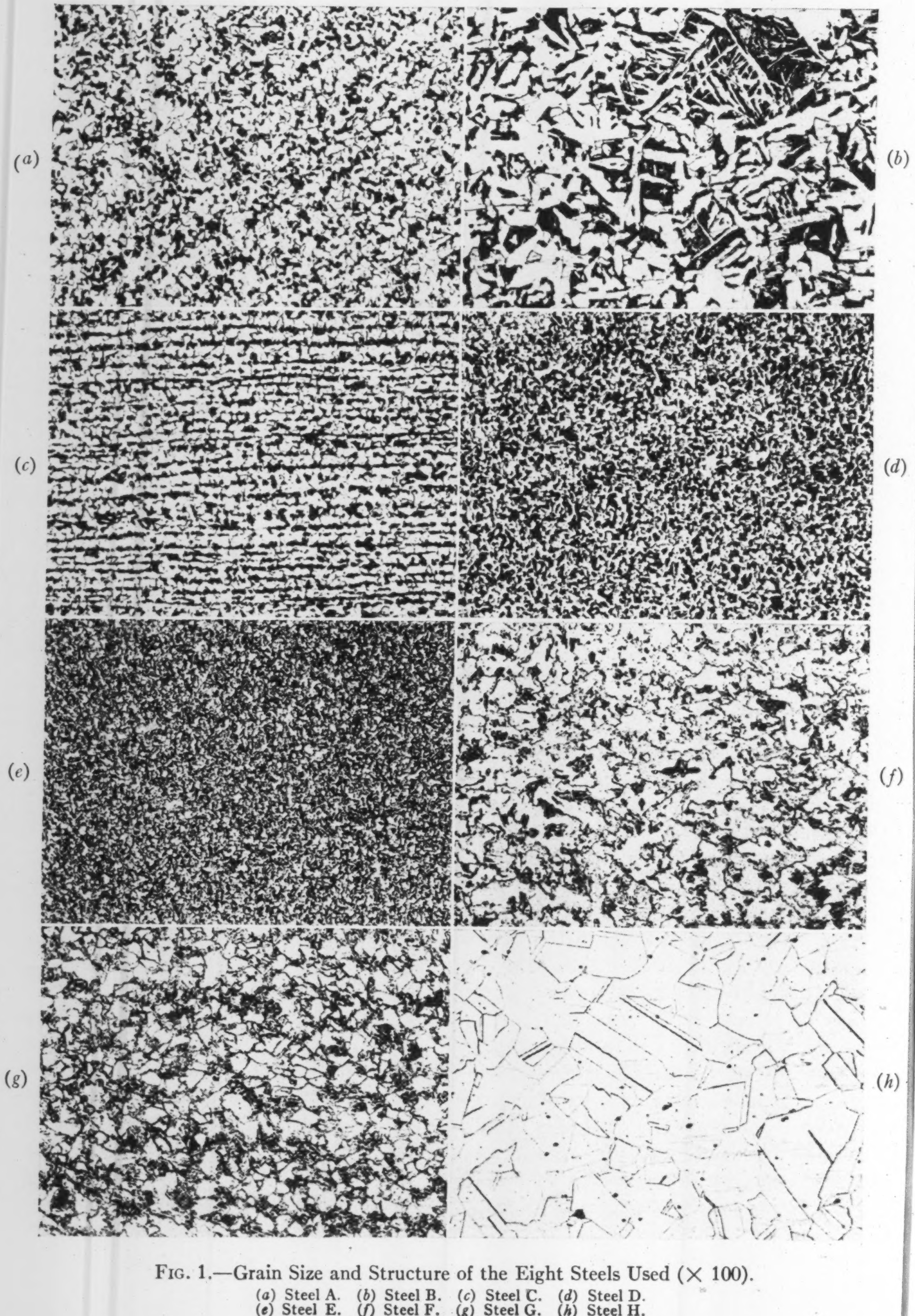

Fig. 1.—Grain Size and Structure of the Eight Steels Used (× 100).
(*a*) Steel A. (*b*) Steel B. (*c*) Steel C. (*d*) Steel D.
(*e*) Steel E. (*f*) Steel F. (*g*) Steel G. (*h*) Steel H.

of the temperatures, as it was desired to establish the relationships between impact values for standard size and sub-size specimens for the various types of steels at the testing temperatures.

DESCRIPTION OF MATERIALS

The compositions and heat treatments for the eight steels included in the program are listed in Table I.

Steels A and B are the S.A.E. X1020 type, steel A having a 5 to 8 grain size, and steel B having a 1 to 3 grain size, as determined by McQuaid-Ehn tests. Steels C and D are S.A.E. X1025 and S.A.E. 1035 types, respectively, both having a 5 to 8 grain size. Preliminary work had shown that a normalizing treatment developed the highest and most uniform sub-zero impact resistance in these straight carbon steels. On that account, steels A, B, C, and D were normalized at the temperatures shown in Table I, before machining the test specimens.

TABLE I.—COMPOSITION AND HEAT TREATMENT OF THE STEELS.

Steel	Composition, per cent								Heat Treatment
	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Molybdenum	
A	0.21	0.89	0.015	0.020	0.22	....	....	....	1650 F., ½ hr., Air cooled.
B	0.18	0.90	0.014	0.029	0.24	....	....	....	1650 F., ½ hr., Air cooled.
C	0.27	0.90	0.016	0.030	0.18	....	....	....	1600 F., ½ hr., Air cooled.
D	0.39	0.80	0.021	0.020	0.19	....	....	....	1515 F., ½ hr., Air cooled.
E	0.15	0.44	0.012	0.029	0.19	3.39	....	....	1500 F., ½ hr., Air cooled; 1200 F., 2 hr., Air cooled.
F	0.12	0.40	0.014	0.011	0.31	....	2.02	0.48	1650 F., 1 hr., Air cooled. 1380 F., 4 hr., Furnace cooled to 1110 F.
G	0.13	0.51	0.022	0.007	0.15	....	5.53	0.48	1600 F., 2 hr., Furnace cooled to 1100 F.
H	0.05	0.46	0.011	0.009	0.34	8.98	17.51	....	1920 F., ½ hr., Water quenched.

Steel E is an S.A.E. 2315 alloy having a grain size of 6 to 8 as determined by McQuaid-Ehn tests. Steel F is a low carbon, 2 per cent chromium, ½ per cent molybdenum alloy. Steel G is a low carbon, 5 per cent chromium, ½ per cent molybdenum alloy. The grain size of steels F and G as determined by McQuaid-Ehn tests was 5 to 7. Steel H is an 18 per cent chromium, 8 per cent nickel alloy. The heat treatments applied to each alloy to develop the highest and most uniform sub-zero impact properties were determined by preliminary work.

Figure 1 shows the actual grain sizes and structures of the eight steels as heat treated preliminary to testing. Steels A, B, C, and D have typical normalized structures of the grades involved, with A, C, and D being fine grained with respect to ferritic grain size and B being somewhat coarse grained. Steel E has a very fine grained structure. Steels F and G have an intermediate grain size. Steel H has a totally austenitic structure and an intermediate grain size.

TEST PROCEDURES

The steels were prepared for heat treatment in the form of flat bars, 2½ in. wide by ½ in. thick, obtained by forging from 3-in. round bars. After heat treating, specimens were machined to provide for testing three specimens of each size at each of the testing temperatures. Figure 2 shows the dimensions and shapes of each specimen size. Steels A, B, C, D, and E were tested at 70 F., −50 F., −75 F., −100 F., −125 F., and −150 F. Steels F, G, and H were tested at 70 F. −25 F., and −50 F.

All specimens were cut longitudinally with respect to the original billet stock. The specimens broken at 70 F. were held at that temperature in an acetone solution for ½ hr. before testing. The specimens broken at temperatures between and including −25 F. to −100 F. were held at temperature in a dry ice - acetone solution for 1 hr. The specimens broken at −125 F. and −150 F. were held at temperature in a liquid nitrogen - acetone solution for 1 hr. In each case, the specimens were transferred to the testing machine with tongs which were otherwise kept in the solutions. All specimens were broken within 6 sec. after removal from their respective solutions.

TABLE II.—STEEL A.

Testing Temperature, deg. Fahr.	Charpy Impact, ft-lb.				
	Standard Size Specimens	⅔ Size Specimens	½ Size Specimens	⅓ Size Specimens	¼ Size Specimens
70	56.77	37.82	30.13	16.49	12.87
	56.77	39.41	28.57	17.72	11.78
	56.77	37.82	30.13	16.49	11.78
Average	56.77	38.35	29.61	16.90	12.14
Percentage of standard	......	67.5	52.2	29.8	21.4
−50	56.77	37.82	28.57	17.72	11.78
	62.27	39.41	28.57	17.72	11.78
	56.77	37.82	28.57	17.72	11.78
Average	58.60	38.35	28.57	17.72	11.78
Percentage of standard	.....	65.4	48.8	30.2	20.1
−75	46.14	37.82	25.67	17.72	11.78
	41.08	31.60	25.67	17.72	11.78
	46.14	36.30	30.13	17.72	11.78
Average	44.45	35.24	27.16	17.72	11.78
Percentage of standard	.....	79.3	61.1	39.9	26.5
−100	34.71	25.67	22.92	19.02	11.78
	37.82	25.67	22.92	17.72	11.78
	36.30	28.57	22.92	17.72	11.78
Average	36.28	26.64	22.92	18.15	11.78
Percentage of standard	.....	73.4	63.2	50.0	32.5
−125	31.60	27.12	24.30	14.10	12.87
	33.12	27.12	21.62	16.49	11.78
	39.41	24.30	21.62	17.72	11.78
Average	34.71	26.18	22.51	16.10	12.14
Percentage of standard	.....	75.4	64.9	46.4	35.0
−150	28.57	22.92	21.62	12.87	11.78
	33.12	24.30	21.62	15.29	11.78
	31.60	22.92	24.30	15.29	11.78
Average	31.10	23.38	22.51	14.48	11.78
Percentage of standard	.....	75.2	72.4	46.6	37.9

The machine used for testing was an Olsen, Charpy pendulum type, unbraked, having the following characteristics:

Weight of head	23 kg.
Radius to point of percussion	75.5 cm.
Radius to center of gravity	70.301 cm.
Height of fall referred to center of gravity	136.362 cm.
Striking velocity	5.3 m. per sec. (17.39 ft. per sec.)
Angle of free swing	160 deg.
Capacity at 0 deg. rise	31.3632 kg-m. (226.85 ft-lb.)
Span between anvils	40 mm. (1.575 in.)
Radius on corners of anvils	0.397 mm. (1/64 in.)

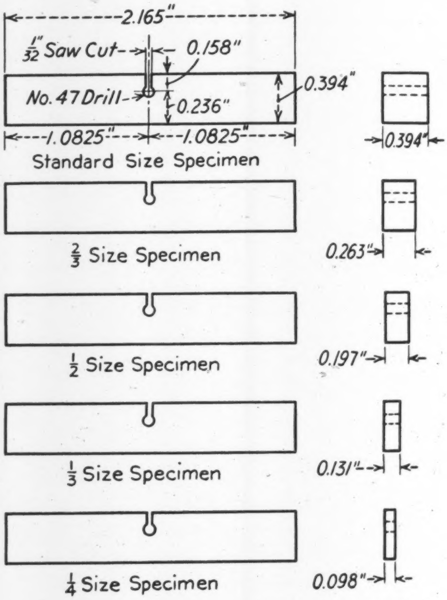

FIG. 2.—Dimensions and Shape of Each Specimen Size.

TEST RESULTS

The results of the tests on steel A are given in Table II. From Table II, it can be noted that the impact values for the ⅔, ½, and ⅓ size specimens at 70 F. and −50 F. have practically the same relationships to the values for the standard size specimens as do their respective sizes, while the ¼ size specimens show values of about 20 per cent. The values for the standard, ⅔, and ½ size specimens decrease as the testing temperature is lowered. The values for the ⅓ and ¼ size specimens are practically constant throughout the temperature range. Since the largest decrease takes place in the largest or standard size specimens, the percentage of the standard value for each sub-size increases as the testing temperature decreases.

The values obtained on steel B are given in Table III. At 70 F., the relationships of the values for the sub-size specimens to the values for the standard size specimens are slightly higher than the similar values of steel A. An outstanding feature of the results on steel B is the rapid decrease of values for standard and ⅔ size specimens at decreasing testing temperatures, as compared to the somewhat constant values for the ⅓ and ¼ size specimens. At testing temperatures below −75 F., the ½, ⅓, and ¼ size specimens gave values higher than the standard and ⅔ size specimens, with but one exception, that being the ½ size at −150 F. Such a combination of values provides for certain sub-size specimens at sub-zero temperatures showing an abnormally high percentage relationship as compared to the values for the standard size specimens.

TABLE III.—STEEL B.

Testing Temperature, deg. Fahr.	Charpy Impact, ft-lb.				
	Standard Size Specimens	⅔ Size Specimens	½ Size Specimens	⅓ Size Specimens	¼ Size Specimens
70	51.42	37.82	28.57	16.49	10.63
	51.42	37.82	28.57	17.72	11.78
	33.16	37.82	28.57	16.49	11.78
Average	45.33	37.82	28.57	16.90	11.40
Percentage of standard	.....	83.4	63.0	37.3	25.1
−50	28.57	28.57	28.57	14.10	9.61
	31.60	28.57	28.57	12.87	10.63
	24.30	28.57	24.30	12.87	11.78
Average	28.16	28.57	27.15	13.28	10.67
Percentage of standard	.....	101.5	96.4	47.2	37.9
−75	31.60	24.30	25.67	12.87	8.61
	24.30	22.92	24.30	11.78	11.78
	19.02	22.92	25.67	11.78	8.61
Average	24.97	23.38	25.21	12.14	9.67
Percentage of standard	.....	93.6	101.0	48.6	38.7
−100	3.06	2.24	15.29	10.63	7.59
	3.06	2.24	20.25	11.78	12.87
	3.06	2.24	17.72	10.63	8.61
Average	3.06	2.24	17.75	11.01	9.69
Percentage of standard	.....	73.2	580.1	359.8	316.7
−125	2.24	2.24	1.47	10.63	9.61
	2.24	2.24	19.02	11.78	7.59
	3.06	2.24	16.49	10.63	7.59
Average	2.51	2.24	12.33	11.01	8.26
Percentage of standard	.....	89.2	491.2	438.6	329.1
−150	3.91	2.24	3.05	10.63	7.59
	3.91	2.24	2.24	10.63	9.61
	3.06	2.24	2.24	10.63	8.61
Average	3.63	2.24	2.51	10.63	8.60
Percentage of standard	.....	61.7	69.1	292.8	236.9

TABLE IV.—STEEL C.

Testing Temperature, deg. Fahr.	Charpy Impact, ft-lb.				
	Standard Size Specimens	⅔ Size Specimens	½ Size Specimens	⅓ Size Specimens	¼ Size Specimens
70	46.14	31.60	27.12	15.29	9.61
	44.48	31.60	25.67	17.72	10.63
	37.82	33.12	25.67	15.29	9.61
Average	42.81	32.11	26.15	16.10	9.95
Percentage of standard	......	75.0	61.1	37.6	23.2
−50	33.12	30.13	24.30	15.29	11.78
	31.60	30.13	22.92	15.29	11.78
	28.57	24.30	19.02	15.29	10.63
Average	31.10	28.19	22.08	15.29	11.40
Percentage of standard	......	90.6	71.0	49.2	36.7
−75	30.13	27.12	21.62	16.49	10.63
	28.57	25.67	20.25	16.49	10.63
	25.67	22.92	19.02	15.29	9.61
Average	28.12	25.24	20.30	16.09	10.29
Percentage of standard	......	89.8	72.2	57.2	36.6
−100	24.30	20.25	17.72	14.10	10.63
	21.62	20.25	17.72	14.10	10.63
	24.30	19.02	16.49	12.87	7.59
Average	23.41	19.84	17.31	13.69	9.62
Percentage of standard	......	84.8	73.9	58.5	41.1
−125	20.25	19.02	15.29	9.61	9.61
	21.62	20.25	16.49	15.29	10.63
	20.25	16.49	17.72	12.87	10.63
Average	20.71	18.59	16.50	12.59	10.29
Percentage of standard	......	89.8	79.7	60.8	49.7
−150	14.10	14.10	15.29	8.61	5.69
	21.62	14.10	12.87	14.10	9.61
	21.62	14.10	14.10	10.63	9.61
Average	19.11	14.10	14.09	11.11	8.30
Percentage of standard	......	73.8	73.7	58.1	43.4

Table IV shows the results of the tests on steel C. At 70 F., the impact values for the ⅔, ½, and ⅓ size specimens are slightly higher than the size ratios as compared to the values for the standard size specimens, while the ¼ size values were slightly lower than the size ratio. At lower testing temperatures, the values for all sizes of specimens decrease, with the greatest percentage of loss in the standard size specimens and the least amount of loss in the ¼ size specimens. As a result, the general trend of the sub-size relationship to the standard size is to increase with respect to percentage of the standard size values.

Table V shows the values obtained on steel D. At 70 F., each sub-size showed a higher relationship of impact value than the ratios for the respective sizes. The standard size specimens showed loss of impact resistance as the temperature decreased to −100 F., while at −125 F. and −150 F. the values began to increase. With but certain exceptions, the sub-size specimens showed decreased values as the testing temperature was decreased. As a result, the percentage relationships to the standard values are almost constant throughout the testing range. The unusual decrease at −100 F. on the standard specimens provides the only unusual feature in the results obtained on steel D.

TABLE V.—STEEL D.

Testing Temperature, deg. Fahr.	Charpy Impact, ft-lb.				
	Standard Size Specimens	⅔ Size Specimens	½ Size Specimens	⅓ Size Specimens	¼ Size Specimens
70	28.57	22.92	17.72	11.78	9.61
	34.71	24.30	22.92	11.78	11.78
	34.71	22.92	19.02	11.78	9.61
Average	32.66	23.38	19.89	11.78	10.33
Percentage of standard	......	71.6	60.9	36.1	31.6
−50	19.02	16.49	14.10	8.61	6.63
	17.72	16.49	12.87	8.61	7.59
	21.62	17.72	12.87	8.61	8.61
Average	19.45	16.90	13.28	8.61	7.61
Percentage of standard	......	86.9	68.3	44.3	39.1
−75	17.72	15.29	10.63	7.59	6.63
	16.49	15.29	12.87	8.61	6.63
	19.02	15.29	10.63	8.61	9.61
Average	17.74	15.29	11.38	8.27	7.62
Percentage of standard	......	86.2	64.1	46.6	43.0
−100	11.78	12.87	10.63	7.59	6.63
	10.63	14.10	9.61	6.63	6.63
	14.10	14.10	11.78	7.59	9.61
Average	12.17	13.69	10.67	7.27	7.62
Percentage of standard	......	112.5	87.7	59.7	62.6
−125	17.72	16.49	5.69	8.61	6.63
	17.72	16.49	11.78	8.61	6.63
	17.72	16.49	10.63	7.59	6.63
Average	17.72	16.49	9.37	8.27	6.63
Percentage of standard	......	93.1	52.9	46.7	37.4
−150	15.29	11.78	11.78	7.59	5.69
	16.49	10.63	9.61	7.59	5.69
	25.67	11.78	9.61	6.63	6.63
Average	19.15	11.40	10.33	7.27	6.00
Percentage of standard	......	59.5	53.9	38.0	31.3

In Table VI are shown the results obtained with steel E. At 70 F., the ⅔, and ½ size values have practically the same relationship to the standard values as the size ratios. The ⅓ and ¼ size values at 70 F. are slightly less in this respect. As was the case with the steels previously described, the standard size values at lower temperatures decreased more rapidly than did the sub-size

TABLE VI.—STEEL E.

Testing Temperature, deg. Fahr.	Charpy Impact, ft-lb.				
	Standard Size Specimens	⅔ Size Specimens	½ Size Specimens	⅓ Size Specimens	¼ Size Specimens
70	51.42	37.82	31.60	19.02	12.87
	58.58	41.08	31.60	17.72	12.87
	62.27	36.30	31.60	17.72	12.87
Average	57.42	38.40	31.60	18.15	12.87
Percentage of standard	......	66.7	55.0	31.6	22.4
−50	44.88	33.12	31.60	17.72	11.78
	56.77	39.41	30.13	17.72	12.87
	51.42	36.30	30.13	16.49	11.78
Average	51.02	36.28	30.62	17.31	12.14
Percentage of standard	......	71.1	60.0	33.9	23.8
−75	44.48	37.82	30.13	17.72	10.63
	51.42	33.12	31.60	17.72	12.87
	47.88	33.12	27.12	17.72	11.78
Average	47.93	34.69	29.62	17.72	11.76
Percentage of standard	......	72.4	61.8	37.0	24.5
−100	47.88	34.71	27.12	19.02	11.78
	44.48	37.82	27.12	15.29	11.78
	39.41	33.12	28.57	16.49	11.78
Average	43.92	35.22	27.60	16.93	11.78
Percentage of standard	......	80.2	62.8	38.5	26.8
−125	37.82	33.12	30.13	19.02	12.87
	56.77	33.12	27.12	16.49	11.78
	39.41	37.82	28.57	16.49	11.78
Average	44.67	34.69	27.61	17.33	12.14
Percentage of standard	......	77.7	61.8	38.8	27.2
−150	41.08	31.60	28.57	17.22	12.87
	46.14	31.60	25.67	16.49	11.78
	44.48	31.60	25.67	16.49	11.78
Average	43.90	31.60	26.64	16.73	12.14
Percentage of standard	......	72.0	60.7	38.1	27.7

values. In fact, the ⅓ and ¼ size values are practically constant throughout the testing range. As a result, the sub-zero relationships of the sub-size values to the respective standard values are slightly greater than the size ratios. An outstanding feature of steel E is the uniformity of test results and relationships throughout the testing range.

TABLE VII.—STEEL F.

Testing Temperature, deg. Fahr.	Charpy Impact, ft-lb.				
	Standard Size Specimens	⅔ Size Specimens	½ Size Specimens	⅓ Size Specimens	¼ Size Specimens
70	54.97	41.08	36.30	21.62	12.87
	67.99	44.48	34.71	21.62	12.87
	67.99	44.48	34.71	21.62	12.87
Average	63.65	43.35	35.24	21.62	12.87
Percentage of standard	......	68.1	55.4	34.0	20.2
−25	53.16	39.41	33.12	21.62	12.87
	51.42	37.82	33.12	21.62	14.01
	54.97	39.41	31.60	21.62	12.87
Average	53.18	38.88	32.61	21.62	13.25
Percentage of standard	......	73.1	61.3	40.7	24.9
−50	46.14	34.71	31.60	19.02	14.01
	47.88	34.71	30.13	20.25	14.01
	41.08	37.82	33.12	20.25	14.01
Average	45.03	35.75	31.62	19.84	14.01
Percentage of standard	......	79.4	70.2	44.1	31.1

TABLE VIII.—STEEL G.

Testing Temperature, deg. Fahr.	Charpy Impact, ft-lb.				
	StandardSize Specimens	⅔ Size Specimens	½ Size Specimens	⅓ Size Specimens	¼ Size Specimens
70	42.74	33.12	25.67	15.29	11.78
	42.74	33.12	25.67	16.49	11.78
	47.88	41.08	30.13	17.72	11.78
Average	44.45	35.77	27.16	16.50	11.78
Percentage of standard	......	80.5	61.1	37.1	26.5
−25	31.60	28.57	25.67	12.87	8.61
	33.12	25.67	24.30	12.87	8.61
	34.71	30.13	24.30	14.10	11.78
Average	33.14	28.12	24.76	13.28	9.67
Percentage of standard	......	84.9	74.7	40.0	29.2
−50	28.57	30.13	22.92	12.87	8.61
	30.13	28.57	22.92	12.87	8.61
	30.13	24.30	22.92	12.87	8.61
Average	29.61	27.67	22.92	12.87	8.61
Percentage of standard	......	93.4	77.4	43.5	29.1

Table VII shows the results of the tests on steel F. At 70 F. the ⅔, ½, and ⅓ size values have practically the same relationship to the standard values as the size ratios, while the ¼ size values are 20 per cent of the standard values. At the lower testing temperatures, the impact resistance of the standard size specimens decreases more than the resistance of the sub-size specimens. As a result, the sub-size values at sub-zero temperatures have higher relationships to the respective standard size values than is the case at 70 F.

The values for steel G are shown in Table VIII. In one respect this steel is similar to steel E in that there is uniformity in the decrease for all sizes of impact specimens as the testing temperature was lowered.

TABLE IX.—STEEL H.

Testing Temperature, deg. Fahr.	Charpy Impact, ft-lb.				
	Standard Size Specimens	⅔ Size Specimens	½ Size Specimens	⅓ Size Specimens	¼ Size Specimens
70	77.68	53.16	39.41	21.62	15.29
	77.68	53.16	37.48	22.92	15.29
	75.72	51.42	39.41	21.62	14.10
Average	77.03	52.58	38.77	22.05	14.89
Percentage of standard	......	68.3	50.3	28.6	19.3
−25	85.56	60.25	44.48	25.67	17.72
	89.54	62.27	44.48	24.30	17.72
	87.51	62.27	44.48	27.12	17.72
Average	87.54	61.60	44.48	25.70	17.72
Percentage of standard	......	70.4	50.8	29.4	20.2
−50	89.54	60.25	44.48	27.12	17.72
	89.54	62.27	46.14	27.12	19.02
	87.51	64.15	46.14	27.12	17.72
Average	88.86	62.22	45.59	27.12	18.15
Percentage of standard	......	70.0	51.3	30.5	20.4

Steel H, an austenitic 18 per cent chromium, 8 per cent nickel alloy, differed from all the other steels when the testing temperature decreased in that the impact values of all sizes increased, as is shown in Table IX. At all temperatures, the values for the ⅔ size specimens were practically ⅔ of the respective standard size values. The

½ size values are about ½ of standard values. The ⅓ and ¼ size specimens showed lower relationships with respect to standard size specimens than were the specimen size ratios.

PERCENTAGE OF STANDARD SIZE RELATIONSHIPS

Table X lists the sub-size relationships in percentage of standard size value as determined by the various tests. Table XI lists the working values indicated by the test results to be applicable to commercial practice. Fundamentally, the determination of the relationships in per cent between standard and sub-size specimens was the object of the investigation.

TABLE X.—SUB-SIZE RELATIONSHIPS IN PER CENT OF STANDARD SIZE VALUE.

Testing Temperature, deg. Fahr.	Size	Steel A	Steel B	Steel C	Steel D	Steel E	Steel F	Steel G	Steel H
70	⅔	67.5	83.4	75.0	71.6	66.7	68.1	80.5	68.3
	½	52.2	63.0	61.1	60.9	55.0	55.4	61.1	50.3
	⅓	29.8	37.3	37.6	36.1	31.6	34.0	37.1	26.6
	¼	21.4	25.1	23.2	31.6	22.4	20.2	26.5	19.3
−25	⅔	....	....	....	....	....	73.1	84.9	70.4
	½	....	....	....	....	....	61.3	74.7	50.8
	⅓	....	....	....	....	....	40.7	40.0	29.4
	¼	....	....	....	....	....	24.9	29.2	20.2
−50	⅔	65.4	101.5	90.6	86.9	71.1	79.4	93.4	70.0
	½	48.8	96.4	71.0	68.3	60.0	70.2	77.4	51.3
	⅓	30.2	47.2	49.2	44.3	33.9	44.1	43.5	30.5
	¼	20.1	37.9	36.7	39.1	23.8	31.1	29.1	20.4
−75	⅔	79.3	93.6	89.8	86.2	72.4	....	....	....
	½	61.1	101.0	72.2	64.1	61.8	....	....	....
	⅓	39.9	48.6	57.2	46.6	37.0	....	....	....
	¼	26.5	38.7	36.6	43.0	24.5	....	....	....
−100	⅔	73.4	73.2	84.8	112.5	80.2	....	....	....
	½	63.2	580.1	73.9	87.7	62.8	....	....	....
	⅓	50.0	359.8	58.5	59.7	38.5	....	....	....
	¼	32.5	316.7	41.1	62.6	26.8	....	....	....
−125	⅔	75.4	89.2	89.8	93.1	77.7	....	....	....
	½	64.9	491.2	79.7	52.9	61.8	....	....	....
	⅓	46.4	438.6	60.8	46.7	38.8	....	....	....
	¼	35.0	329.1	49.7	37.4	27.2	....	....	....
−150	⅔	75.2	61.7	73.8	59.5	72.0	....	....	....
	½	72.4	69.1	73.7	53.9	60.7	....	....	....
	⅓	46.6	292.8	58.1	38.0	38.1	....	....	....
	¼	37.9	236.9	43.4	31.3	27.7	....	....	....

At 70 F., −25 F., −50 F., and −75 F., working values for ⅔ and ½ size specimens are indicated to be in the same relationship to standard size values as are the size ratios. At −100 F. and −125 F., the working value of ⅔ size specimens apparently can be increased to 70 per cent of the standard size value. At −150 F. the working value of the ⅔ size specimens is indicated as decreasing to 60 per cent of the standard size value. At −100 F., −125 F. and −150 F., the ½ size working value is the same as for the higher temperatures, namely, 50 per cent of the standard size value.

TABLE XI.—WORKING VALUES IN PER CENT OF STANDARD VALUE.

Testing Temperature, deg. Fahr.	Size of Charpy Specimen	Working Values, per cent of standard value
70	⅔; 0.263 by 0.394 in.	66.7
	½; 0.197 by 0.394 in.	50.0
	⅓; 0.131 by 0.394 in.	25.0
	¼; 0.098 by 0.394 in.	20.0
−25	⅔	66.7
	½	50.0
	⅓	25.0
	¼	20.0
−50	⅔	66.7
	½	50.0
	⅓	30.0
	¼	20.0
−75	⅔	66.7
	½	50.0
	⅓	33.3
	¼	20.0
−100	⅔	70.0
	½	50.0
	⅓	35.0
	¼	25.0
−125	⅔	70.0
	½	50.0
	⅓	35.0
	¼	25.0
−150	⅔	60.0
	½	50.0
	⅓	35.0
	¼	25.0

The working values for the ⅓ size specimens are indicated to increase from 25 per cent at 70 F. and −25 F. to 30 per cent at −50 F., 33.3 per cent at −75 F., and to 35 per cent at −100 F., and −125 F. and −150 F.

The ¼ size specimens appear to have a 20 per cent relationship at 70 F., −25 F., −50 F., and −75 F. At lower testing temperatures, the relationship for $\frac{1}{4}$ size specimens is indicated to be increased from 20 per cent to 25 per cent.

SUMMARY

Probably the most significant points in the test data are the increases at sub-zero temperatures of the percentage values for the small size Charpy specimens with respect to values for standard size Charpy specimens and the constancy of the values for the $\frac{1}{3}$ and $\frac{1}{4}$ size specimens throughout the testing range. In fact, one could interpret that testing of $\frac{1}{3}$ and $\frac{1}{4}$ size specimens is needless, since values for $\frac{1}{3}$ size specimens range between 10 and 20 ft-lb., while values for $\frac{1}{4}$ size specimens range between 5 and 15 ft-lb., regardless of the type of steel or the testing temperature. On the other hand, the values for standard and $\frac{2}{3}$ size specimens varied considerably. The values for $\frac{1}{2}$ size specimens, as a rule, followed the trend of the larger specimens, in that there was a decrease at lower testing temperatures. However, the amount of decrease for the $\frac{1}{2}$ size specimens was not so pronounced as with the larger specimens.

An interesting feature is the difference in the test results for the S.A.E. X1020 steels, namely, steels A and B. Steel A, a fine-grain type, showed exceptionally good sub-zero impact resistance on all sizes of specimens. Steel B, a coarse-grained type, showed good impact resistance for small size specimens and practically no impact resistance for large size specimens at the lower temperatures. As a result of such a combination, steel B shows rather abnormal relationships for standard and sub-size specimens.

A comparison of steels C and D, S.A.E. X1025 and 1035, respectively, with steel A, indicates that increasing carbon content produces a decrease in impact resistance. All three steels were fine grained. The low values at −100 F. on standard specimens of steel D indicate that sub-zero working values in foot-pounds for the higher carbon grades should not be established at levels as high as those for the low-carbon grades.

The value of nickel with respect to sub-zero impact resistance is demonstrated with steel E. Even at −150 F., its impact resistance was exceptionally good. Apparently, nickel tends to act as a stabilizer of sub-zero impact resistance, as the most uniformity between all specimen sizes at all temperatures was obtained with steel E.

The low chromium content steels F and G are ordinarily expected to have an impact value of 20 ft-lb. at −25 F. The superiority of a combination normalizing and drawing treatment over a single furnace anneal, with respect to sub-zero impact resistance, is partially demonstrated by the difference in the values obtained for both steels. However, it is not always desirable to apply a normalizing drawing treatment to steel G. The reverse is true for steel F.

As was to be expected, the 18 per cent chromium, 8 per cent nickel alloy or steel H showed increasing impact resistance with decreasing temperature. The excellent impact resistance of 18-8 alloy is too well known to warrant comment.

Perhaps the most plausible explanation for certain steels showing either greater impact resistance or higher percentage relationships on small size specimens than on large size specimens at certain testing temperatures is that given by Moser[2] who shows that certain steels had decreased impact resistance when the specimen size was increased. He found that if proportional results were to be obtained from proportional sizes of specimens, factors which had to be considered are the actual working volumes of metal which participate in the absorption of energy and the ratio of the speed of impact to the velocity of the strain propagation of the material. By adjusting the speed of impact for each specimen size so as to provide maximum working volumes for the absorption of energy, Moser obtained straight-line relationships between impact resistance and specimen sizes on steels, which when tested with a constant speed of impact had yielded disproportionate values for proportional size specimens.

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[2] M. Moser, "A New Method of Interpreting Notched Bar Impact Test Results," *Transactions*, Am. Soc. Steel Treating, Vol 7, March, 1925, p. 297.

On the basis of Moser's data, it is indicated that the speed of impact used in this investigation provided for maximum working volumes in the $\frac{1}{3}$ and $\frac{1}{4}$ size specimens so that the impact values remained fairly constant throughout the testing range. As the specimen size increased, the working volume for the same speed of impact was probably decreased. It is also possible that at the lower testing temperatures, the working volumes on the large size specimens were further decreased. Such a combination of conditions would explain either the greater impact resistance or the higher percentage relationships of the sub-size specimens at certain testing temperatures. However, there can be no doubt about certain steels losing impact resistance as measured on large size specimens when the testing temperature is decreased. On that account, the impact test, if large size specimens are used, is a measure of low-temperature brittleness for a given set of conditions.

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FACTORS AFFECTING NOTCHED-BAR IMPACT TESTS ON STEEL AT LOW TEMPERATURES

By Walter Crafts[1] and John J. Egan[1]

Synopsis

In order to determine the reasons for lack of correlation between different makes of Charpy and Izod-type impact testing machines in tests at low temperatures, a survey has been made to evaluate some of the variables that might produce the differences. Tests at low temperatures of both Izod and Charpy types were made on a machine in which the initial energy and velocity of blow could be varied independently. The notch radius and depth were also investigated to estimate sensitivity to accuracy of the specimen dimensions. The length of cantilever arm of an Izod machine was also studied. The results indicated a general, but not extremely accurate, correlation between different makes of machines, and a conservative use of the test for specification purposes is recommended.

Due to the increased application of pearlitic steels at sub-zero temperatures it has become desirable to establish a criterion of the degree of toughness residual in the steel at the temperature of service. The notched-bar impact test has been widely used to determine this, and it has been considered that minimum average values of 15 ft-lb. Charpy and 18 ft-lb. Izod at −18 to 60 C. (0 to 76 F.)[2] should be used as a specification of adequate toughness. Due to the fact that impact strength drops discontinuously with temperature and that the commonly specified minimum values are in a very critical range, it is difficult to obtain a true average value. Furthermore, it was indicated by the tests carried out by Subcommittee P of Committee III on Projects of the Joint A.S.M.E.-A.S.T.M. Research Committee on Effect of Temperature on the Properties of Metals[3] that different testing machines revealed the break to lower impact strength at widely varying temperatures. In that investigation critical temperature varied from −46 to −3.9 C. (−50 to +25 F.) depending on which testing machine was used. In order to determine the more critical factors governing the discrepancy, the following study of testing variables has been carried out to include initial energy, velocity, and specimen dimensions.

Review of the Literature

A review of published investigations of the notched-bar impact test has shown that testing was usually carried out at room temperature in ranges in which the steel was relatively insensitive to the change of testing conditions, and the observations and conclusions have offered little help to the solution of the low-temperature problem in which the tests must be carried out in a critical range of transition from the tough to the brittle condition. Extensive reviews of these investigations have been compiled by McAdam,[4] Hoyt,[5] and others.

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[1] Research Metallurgists, Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y.

[2] Paragraph U-142; Addenda to A.S.M.E. Code for Unfired Pressure Vessels, Section VIII, A.S.M.E. Boiler Construction Code.

[3] General Summary and Comparison of Procedure and Results Obtained on Cooperative Study of Low-Temperature Impact Testing of 0.35 per cent Carbon Steel (K20), Summarized by R. Sergeson and S. W. Poole, *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 132 (1936).

Early work on the impact test led many investigators to believe that the type of machine was of comparatively little importance. Fremont[6] in 1912 reported that variations in results obtained in different simple beam tests on machines of the drop hammer and pendulum types were due to energy losses to the machine, such as in the use of excessively light anvils. In 1917 Charpy and Cornu-Thenard[7] after an extensive series of simple beam impact tests using machines of the pendulum, drop hammer, and rotary types also reported that the energies absorbed in all machines in fracturing specimens of a given steel were identical when the size of the test specimen, notch depth, and other factors were uniform. Philpot[8] using both a Charpy and an Izod machine found that when the energy absorbed was less than 70 ft-lb. no difference could be noted between the values obtained on the two machines. Above 70 ft-lb., however, the Charpy machine tended to give somewhat higher values. McAdam[4] has quoted the British Engineering Standards "Report on the British Standard Forms of Notched Bar Test Pieces" thus: "The results in some materials depend on the striking velocity which should not in any case be less than 3 m. per sec. [9.84 ft. per sec.]. . . . Various machines are used for making notched-bar tests. It does not appear that the results are materially different when tests are made with the standard types of test piece in these different machines provided they are properly constructed, calibrated and used, and that the striking velocity is not substantially different."

Although considerable work has been reported on the effect on impact resistance of variations in notch root radius, few systematic researches have been described, particularly in the earlier literature. Mailänder[9] has presented Charpy data on specimens with notch radii of 1, 2, and 4 mm. and depths of 2, 3, and 5 mm. Little difference was found to exist in the low and medium impact strength ranges in the specimens notched to 3 and 5-mm. depths. In the case of steels showing greater toughness, however, a much greater spread in values was noted. Burns[10] found that changes in radius from 0.25 to 0.50 mm. on Izod specimens had relatively little effect when the notch depth was 3 mm. and over. The effects of variations in notch depth in Charpy specimens have been discussed at length by Mailänder,[9] Dupuy,[11] Steccanella[12] and others. In general their choice was a notch of the U type with root radius of 1 mm. (0.039 in.), although some work was reported with a V notch having root radius of 0.25 mm. (0.01 in.). The objection to shallow notches was found to lie in the fact that with tough steels the hammer, having insufficient energy to break the specimen, might tend to be stopped in its fall and cause some deterioration to the machine, in addition to giving unsatisfactory shock resistance readings on the steel being tested. The use of the more acute V notch was recommended for steels of this tough variety.

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[4] D. J. McAdam, Jr., "Impact Tests of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 22, Part II, p. 37 (1922).

[5] S. L. Hoyt, "Notched Bar Testing," *Metals and Alloys*, Vol. 7, pp. 5, 39, 102, 140 (1936).

[6] C. Fremont, "Testing Metals by Impact," *Proceedings*, Internat. Assn. Testing Mats., Sixth Congress, N. Y., First Section, Part IV2 (1912).

[7] G. Charpy and A. Cornu-Thenard, "New Experiments on Shock Tests," *Journal*, Iron and Steel Inst., Vol. 96, p. 61 (1917).

[8] H. T. Philpot, "Some Experiments on Notched Bars," *Proceedings*, Inst. Automobile Engrs., April, 1918. Abstracted in *Engineer*, Vol. 125, p. 338 (1918); *Journal*, Soc. Automotive Engrs., Vol. 3, p. 347, (1918).

[9] R. Mailänder, "International Standardization of Impact Specimens," *Stahl und Eisen*, Vol. 55, p. 1456 (1935).

[10] G. Burns, "Notched Bar Impact Tests," *Metallurgist*, December 27, 1935, p. 86.

[11] E. Dupuy, J. Mellon, and P. Nicolau, "International Standardization of the Shock Bend Test on Notched Bars," *Revue de Métallurgie*, Vol. 33, pp. 55, 133 (1936).

[12] A. Steccanella, "Standardization of the Notched Bar Test Piece," *La Metallurgia Italiana*, May 1932, September 1933, February 1935; English summary in *Metallurgist*, October 25, 1935, p. 75.

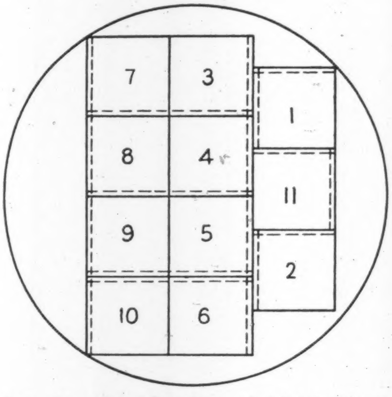

FIG. 1.—Cross-Section of $2\frac{1}{2}$-in. Diameter Bar Showing Method of Cutting and Notching Specimens. Dotted lines indicated notches.

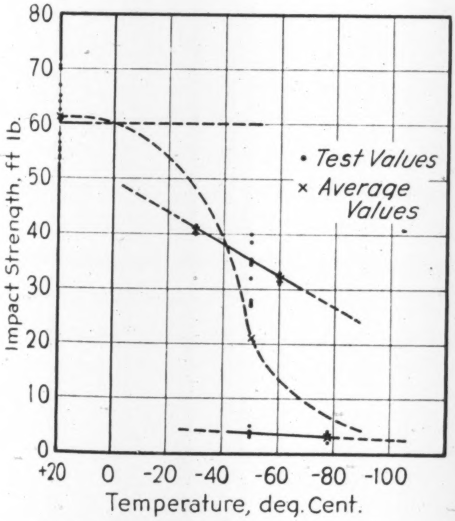

FIG. 2.—Effect of Temperature on Standard Charpy Impact Strength (Machine A).

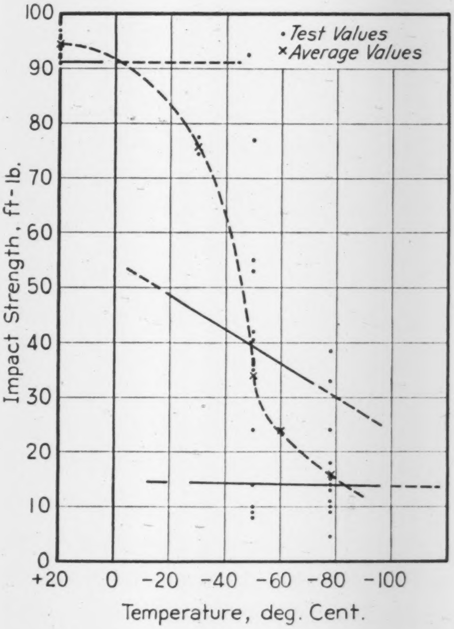

FIG. 3.—Effect of Temperature on Standard Izod Impact Strength (Machine A).

TABLE I.—INFLUENCE ON IMPACT STRENGTH OF POSITION IN CROSS-SECTION OF BAR.

Location[a] Room Temperature		Location[a] −50 C.		Location[a] −78 C.	
STANDARD CHARPY—MACHINE A					
8L	67.0	4R	4.0	9L	2.9
B	56.5	B	32.2	B	3.4
5R	65.0	1L	35.0	2T	3.1
B	58.0	B	34.8	L	2.9
7L	62.5	10T	35.4	6T	2.8
B	58.0	L	38.5	R	3.7
STANDARD IZOD—MACHINE A					
8L	90.8	4R	40.5	9L	15.0
B	92.3	B	34.0	B	10.0
5R	92.5	1L	42.0	2T	9.0
B	92.5	B	14.0	L	14.0
		10T	37.0	6T	24.5
		L	55.0	R	9.0

[a] Location of notch with respect to number on end of specimen (see diagram in Fig. 1):
R = right, L = left, T = top, B = bottom.

The effect of velocity on impact strength has been a subject of interest from the time of the development of the earliest form of impact testing. Ehrensberger[13] in 1907, and Guillet and Revillon[14] in 1909, using respectively pendulum and rotary machines, reported that little significant effect could be noted up to a striking velocity of 10 m. per sec. (32.8 ft. per sec.). Their conclusions were verified by Charpy and Cornu-Thenard in 1917[7] and by Philpot[8] in 1918. During the intervening period, however, other investigators were of a different opinion. Among these were Fremont[6] and the laboratories of the Paris-Lyon-Mediterranee Railroad[15] whose results indicated the existence of a velocity factor.

EXPERIMENTAL INVESTIGATION

The steel used in this study was all taken from a single 2½-in. diameter bar of S. A. E. 1020X steel with a McQuaid-Ehn grain size of No. 6 to 8, and having the following composition: carbon 0.21 per cent, manganese 0.85 per cent, phosphorus 0.029 per cent, sulfur 0.020 per cent, silicon 0.24 per cent. The impact specimens were cut as shown in Fig. 1. As indicated in Table I, the location in the bar produced no significant differences in impact strength. A heat treatment that had given consistently reliable results on similar steels, namely, normalizing after 3 hr. at 900 C. and drawing for 3 hr. at 650 C. with air cooling, was used. The effect of temperature on the standard Charpy impact strength and the standard Izod impact strength is illustrated in Figs. 2 and 3, respectively. The testing temperatures, room, −50, and −78 C., were chosen so that the critical drop to low values would occur within the testing range. With decrease in temperature, typically[3] abrupt transitions to lower levels of energy were observed.

Most of the tests were made in a machine (designated *A*) on which beam or cantilever tests could be carried out by a simple change of the vise and striking edge, while variations in velocity or initial energy were accomplished by changing the hammer and the height of fall as indicated in Table II. Standard simple beam and cantilever tests were, however, also carried out on two other machines of different manufacturers, listed as *B* and *C*, respectively, in the tables. With the exception of those tests conducted on specimens of various widths, all test specimens were 10 mm. square with notches of the dimensions noted. These were milled with a fly cutter, and carefully ground to match templates prepared for each type of notch. In general two breaks were made for any given set of conditions, although at times the number was increased. It is recognized that more values are required to establish the impact strength, but in this case closely comparable values gave correlative checks.

TABLE II.—MACHINE CHARACTERISTICS.

Energy, ft. lb.	Velocity, ft. per sec.	Height of Drop, in.	Weight of Pendulum, lb.
MACHINE A			
110	9.0	15 ¼	86.52
110	12.8	30 ½	43.26
110	18.1	61	21.63
220	12.8	30 ½	86.52
220	18.1	61	43.26
MACHINE B			
223.6	16.9	52.87	50.76
MACHINE C			
120	11.2	24.0	60.0

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[13] H. C. Ehrensberger, "The Impact Test in Material Testing," *Stahl und Eisen*, Vol. 27, p. 1797 (1907).

[14] L. Guillet and L. Revillon, "New Hot Impact Tests on Plain and Special Steels," *Revue de Métallurgie*, Vol. 6, p. 908 (1909).

[15] "Communication from the Testing Laboratory for Metals of the Paris-Lyon-Mediterranee Ry. Co.," *Proceedings*, Internat. Assn. Testing Mats., Sixth Congress, N. Y., First Section, Part IV5 (1912).

It has been shown photoelastically and otherwise that the effect of the shape of the lips of a notch is comparatively slight due to the manner in which the lines of force bend around the apex of the notch. Thus a U or keyhole notch may be opened to a V without significant effect. This was shown by Thomas[16] who prepared specimens with a notch angle of 60 deg. without affecting his results. The point was also checked by the authors in a series of

TABLE III.—COMPARISON OF NOTCH TYPES.
Machine A.

Type of Notch	Notch Depth	Notch Root Radius	Manner of Support	Room Temperature	−50 C.	−78 C.
			0.079-IN. DEPTH			
Keyhole	0.079	0.039	Simple beam (Charpy)	175.0 136.0	72.0 93.0	3.0 3.0
V	0.079	0.039	Simple beam (Charpy)	187.0 172.0	75.5 85.0	12.5 10.8
U	0.079	0.039	Simple beam (Charpy)	161.0 155.0	85.5 78.5	4.0 4.0
Keyhole	0.079	0.039	Cantilever (Izod)	101.5 103.5	95.0 96.5	63.5 63.0
V	0.079	0.039	Cantilever (Izod)	103.3 104.5	79.0 97.8	88.0 86.0
U	0.079	0.039	Cantilever (Izod)	103.2 99.0	89.0 83.5	88.0 54.5
			0.139-IN. DEPTH			
Keyhole	0.139	0.039	Simple beam (Charpy)	91.5 84.0	4.0 4.0	3.0 3.0
V	0.139	0.039	Simple beam (Charpy)	84.0 91.0	41.5 41.5	4.0 3.5
U	0.139	0.039	Simple beam (Charpy)	84.0 110.0	46.0 43.0	3.0 3.0
Keyhole	0.139	0.039	Cantilever (Izod)	54.0 51.5	47.5 43.0	35.5 34.0
V	0.139	0.039	Cantilever (Izod)	67.5 65.0	49.0 49.0	42.0 50.0
U	0.139	0.039	Cantilever (Izod)	70.0 69.2	72.5 55.5	47.0 46.0
			0.199-IN. DEPTH			
Keyhole	0.199	0.039	Simple beam (Charpy)	70.0 58.0	27.5 5.0	3.0 3.2
V	0.199	0.039	Simple beam (Charpy)	68.0 67.5	4.8 35.0	2.8 3.0
U	0.199	0.039	Simple beam (Charpy)	56.0 55.5	4.2 4.0	3.0 3.0
Keyhole	0.199	0.039	Cantilever (Izod)	38.0 37.0	38.0 30.0	28.0 5.0
V	0.199	0.039	Cantilever (Izod)	40.0 40.0	43.0 41.5	29.0 27.5
U	0.199	0.039	Cantilever (Izod)	38.0 38.0	41.5 39.5	25.0 21.0

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[16] J. J. Thomas, "The Charpy Impact Test on Heat-Treated Steels," *Proceedings*, Am. Soc. Testing Mats., Vol. XV, Part II, p. 62 (1915).

tests made on specimens with V, U, and keyhole type notches, the depths and root radii being in all cases identical.

TABLE IV.—IMPACT STRENGTH UNDER VARYING CONDITIONS.
Machine A.

Specimen	Notch Root Radius, in.	Notch Depth, in.	Initial Energy, ft-lb.	Velocity of Blow, ft. per sec.	Impact Strength, ft-lb.		
					Room	−50 C.	−78 C.
SIMPLE BEAM (CHARPY).							
No. 1	0.01	0.079	110	9.0	109.6	41.0	36.0
					109.6	40.0	36.0
No. 2				12.8	105.3	7.5	4.0
					102.0	8.5	4.5
No. 3				18.1	(Stopped hammer)	9.3	3.8
						6.5	5.0
No. 5			220	12.8	130.0	40.0	39.0
					127.0	42.0	37.0
No. 6				18.1	121.0	9.5	5.0
					140.5	7.5	5.0
No. 13		0.139	110	9.0	102.6	44.0	35.0
					102.0	40.0	35.0
No. 14				12.8	89.0	5.5	3.0
					72.5	5.0	4.3
No. 15				18.1	92.5	6.1	3.8
					77.8	4.5	4.3
No. 17			220	12.8	98.0	38.0	34.0
					104.0	38.0	....
No. 18				18.1	84.0	4.5	3.3
					71.4	6.0	3.0
No. 25		0.199	110	9.0	91.4	41.0	36.0
					73.0	43.0	34.0
No. 26				12.8	51.0	4.0	3.0
					56.0	5.0	2.5
No. 27				18.1	52.8	5.3	3.3
					50.0	4.3	3.8
No. 29			220	12.8	75.0	40.0	34.0
					191.2	40.0	35.0
No. 30				18.1	53.0	3.8	2.7
					59.5	3.5	2.8
						3.5	3.0
						3.5	2.8
No. 7	0.039	0.079	110	9.0	(Stopped hammer)	(Stopped hammer)	81.0
							80.0
No. 8				12.8	104.3	94.3	54.5
					104.0	106.3	29.0
No. 9				18.1	(Stopped hammer)	58.5	9.0
						77.5	11.0
No. 11			220	12.8	170.0	103.0	49.0
					186.6	93.0	55.0
No. 12				18.1	187.0	75.5	12.5
					172.0	85.0	10.8
No. 19		0.139	110	9.0	(Stopped hammer)	82.0	56.0
						85.0	54.0
No. 20				12.8	86.8	63.5	7.5
					100.3	57.5	4.0
No. 21		0.139	110	18.1	84.5	57.5	4.3
					76.8	38.3	3.8
No. 23			220	12.8	96.0	64.0	36.0
					99.0	79.0	49.0
No. 24				18.1	84.0	41.5	4.0
					91.0	41.5	3.5
No. 31		0.199	110	9.0	88.0	58.0	37.0
					90.0	62.0	56.0
No. 32				12.8	51.0	31.5	28.0
					60.0	40.0	5.0
No. 33				18.1	57.8	4.0	3.5
					56.8	34.0	4.0
No. 35			220	12.8	73.0	62.0	48.0
					67.0	62.0	33.0
No. 36				18.1	68.0	4.8	2.8
					67.5	35.0	3.0
					63.0	35.5	4.8
					60.0	32.0	2.8

A study of the data shown in Table III bore out Thomas' conclusions, and as a result V notches were chosen for all subsequent tests as being the most economical to prepare.

In carrying out the sub-zero tests, the specimens were brought to the de-

TABLE V.—IMPACT STRENGTH UNDER VARYING CONDITIONS.

Machine A. Cantilever (Izod).

Specimen	Notch Root Radius, in.	Notch Depth, in.	Initial Energy ft-lb.	Velocity of Blow, ft. per sec.	Impact Strength, ft-lb.		
					Room	−50 C.	−78 C.
No. 1	0.01	0.079	110	9.0	90.0	42.0	34.0
					92.5	56.0	15.0
					91.0	37.0	30.0
					90.0	56.4	18.0
No. 2				12.8	90.8	40.5	15.0
					92.3	34.0	10.0
					92.5	42.0	9.0
					92.5	14.0	14.0
					92.0	37.0	24.5
					95.5	55.0	9.0
					93.8	53.0	11.2
					93.5	77.0	13.0
					93.5	10.0	33.0
						36.5	38.5
No. 3				18.1	83.8	84.0	20.0
					93.0	41.3	28.0
					93.8	24.0	28.0
					90.3	39.0	6.5
No. 5			220	12.8	88.0	38.0	35.0
					87.0	31.0	16.0
					92.0	42.0	10.0
					90.0	33.0	9.0
No. 6				18.1	91.8	32.0	17.0
					94.0	38.5	11.0
					94.5	33.5	9.0
					92.0	34.0	9.5
No. 13		0.139	110	9.0	61.0	16.0	9.0
					59.0	25.0	6.0
No. 14				12.8	64.5	17.5	6.5
					61.0	9.5	6.5
No. 15				18.1	60.0	23.8	5.3
					61.3	8.8	7.8
No. 17			220	12.8	59.0	10.0	6.0
					56.0	21.0	9.0
No. 18				18.1	53.0	9.0	6.0
					60.0	14.5	6.3
No. 25		0.199	110	9.0	36.0	16.0	9.0
					34.0	17.0	5.5
No. 26				12.8	40.5	22.5	3.5
					40.0	19.5	6.5
						20.0	13.0
						21.5	4.5
No. 27				18.1	37.5	10.3	6.5
					38.0	7.3	7.0
No. 29			220	12.8	35.0	9.0	6.0
					35.0	18.0	4.0
No. 30				18.1	37.5	15.5	3.5
					37.5	16.0	3.5
No. 7	0.039	0.079	110	9.0	98.6	99.0	71.0
					95.6	90.0	76.0
No. 8				12.8	103.3	79.0	88.0
					104.5	97.8	86.0
No. 9				18.1	95.0	90.0	79.3
					94.8	85.8	62.3
No. 11			220	12.8	94.0	87.0	94.0
					98.0	84.0	74.0
No. 12				18.1	98.0	86.0	82.0
					99.5	86.0	62.0
No. 19		0.139	110	9.0	63.6	56.0	47.0
					62.0	50.6	52.0
No. 20				12.8	67.5	49.0	42.0
					65.0	49.0	50.0
No. 21				18.1	62.8	55.0	43.8
					61.5	54.3	51.8
No. 23			220	12.8	63.0	47.0	47.0
					63.0	55.0	43.0
No. 24				18.1	62.5	62.5	48.5
					65.0	53.5	43.0
No. 31		0.199	110	9.0	40.5	39.0	33.0
					39.0	34.5	34.0
					41.0	36.0	30.0
					37.5	37.0	33.0
No. 32				12.8	41.0	44.5	30.0
					40.0	40.0	32.0
					40.0	43.0	29.0
					38.5	33.0	26.5
					42.0	41.5	29.5
					42.0	38.5	30.0
					40.0	38.5	27.5
					42.3	37.0	34.0
No. 33				18.1	41.8	35.0	29.5
					41.8	41.8	31.5
					40.5	41.0	31.5
					40.5	32.5	30.0
No. 35			220	12.8	40.0	38.0	31.0
					39.0	37.0	34.0
					42.0	38.0	38.0
					40.0	36.0	29.0
No. 36				18.1	42.0	34.5	34.5
					40.5	29.0	29.0
					38.0	36.5	34.0
					40.0	37.0	33.0

sired temperature in acetone cooled with dry ice. Immersion for 30 min. was followed by a quick transfer to the testing machine with immediate release of the hammer. Stop watch measurements showed that the complete operation was carried out in less than 5 sec. Temperature losses during this period have been shown by many investigators to be negligible.

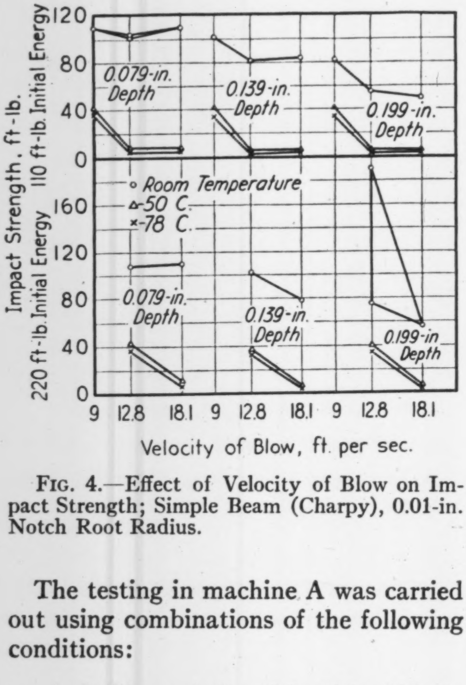

FIG. 4.—Effect of Velocity of Blow on Impact Strength; Simple Beam (Charpy), 0.01-in. Notch Root Radius.

The testing in machine A was carried out using combinations of the following conditions:

1. Striking velocity—9.0, 12.8, 18.1 ft. per sec.
2. Initial energy—110 and 220 ft-lb.
3. Notch depth—0.079, 0.139, and 0.199 in.
4. Notch radius—0.01 and 0.039 in.
5. Temperature—room, −50 C., and −78 C.

The test data are shown in Table IV for specimens loaded as a simple beam under the Charpy conditions and in Table V for specimens broken under cantilever loading according to the Izod method. Each type of loading is discussed separately with respect to variation in the testing conditions.

RESULTS OF SIMPLE BEAM TESTS (CHARPY METHOD)

Increase in the velocity from 9.0 or 12.8 to 18.1 ft. per sec., as shown in Figs. 4 and 5, tended to reduce considerably the low temperature impact strength. It will be seen that at 110 ft-lb. initial energy with the 0.01-in. radius notch an increase from 9.0 to 12.8 ft. per sec. was sufficient to eliminate values in the intermediate range, that is, to shift the critical temperature in which there is a change in the character of the fracture to a range between −50 C. and room temperature. At 220 ft-lb. initial energy with the 0.01-in. radius notch a similar change occurred between 12.8 and 18.1 ft. per sec. With the 0.039-in. radius notch the critical temperature range was maintained around −50 to −78 C. In this case consistently lower values were evident with increased velocity. It should be noted that increased velocity had a minor effect at room temperature when the steel was tough

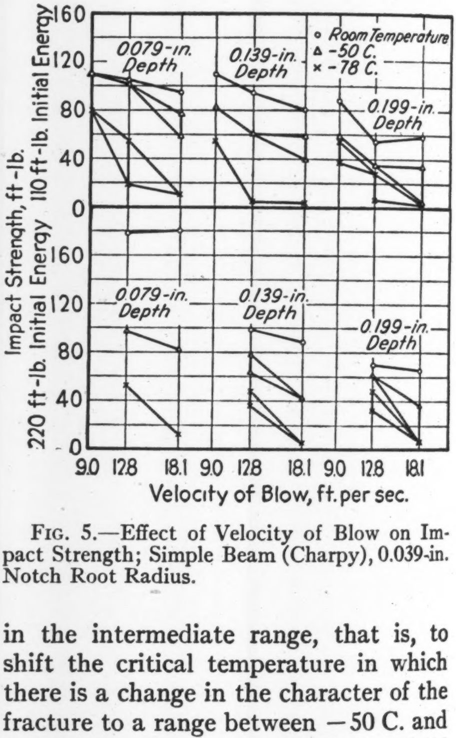

FIG. 5.—Effect of Velocity of Blow on Impact Strength; Simple Beam (Charpy), 0.039-in. Notch Root Radius.

but had no significant influence at low temperatures. The effect was noticeable only in the critical range of intermediate values. The effect of increased velocity is therefore primarily evident in a shift of the critical range to slightly higher temperatures and, to a minor degree, in a lowering of high impact values.

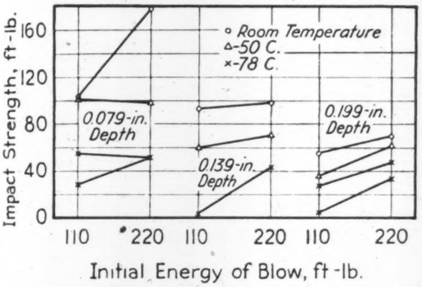

FIG. 6.—Effect of Initial Energy of Blow on Impact Strength; Simple Beam (Charpy), 0.039-in. Notch Root Radius, 12.8 ft. per sec. Velocity of Impact.

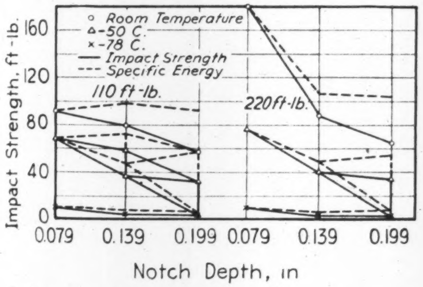

FIG. 7.—Effect of Notch Depth on Impact Strength; Simple Beam (Charpy), 0.039-in. Notch Root Radius, 18.1 ft. per sec. Velocity of Blow.

Increase of initial energy tended to raise the impact values, especially with deep notches, as illustrated in Fig. 6. A correlative observation was that in many cases increases of initial energy and velocity resulting when the same pendulum was simply raised higher, tended to compensate for each other so that values of a similar order were obtained with the same hammer regardless of initial height.

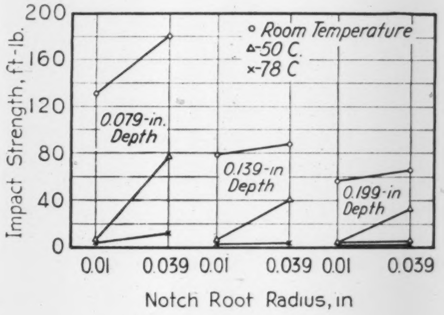

FIG. 8.—Effect of Notch Root Radius on Impact Strength; Simple Beam, 18.1 ft. per sec. Velocity of Impact, 220 ft-lb. Initial Energy of Blow.

TABLE VI.—TEST DATA FOR SIMPLE BEAM (STANDARD CHARPY).

Machine B

Room Temperature	−50 C.	−78 C.
60.9	36.8	7.6
57.4	32.2	7.7
51.8	29.4	7.7
60.9	33.8	7.6
55.5	40.2	7.6
68.5	32.2	14.5
62.7	32.2	7.5
62.7	36.8	7.5
60.1 Avg.	34.2 Avg.	8.5 Avg.

Under the Charpy type loading, the 0.079-in. notch was so shallow that sufficient energy could not always be developed to break the specimen, and even under the latter conditions the impact strength was abnormally high. With few exceptions the absorbed energy tended to be proportional to the area broken, as indicated in Fig. 7. There was, however, a slight tendency for the specific energy values to decrease with greater notch depth. It would appear that, in general, as long as a critical depth is exceeded, notch depth does not appreciably change the temperature limits of the critical range. When the notch depth was sufficient, an increase from 0.01 to 0.039-in. radius produced only a very small increase in the very low and very high impact values but had a material influence on those in the intermediate range (Fig. 8). The effect was of a similar order to that produced by change of velocity and initial energy. With the 0.01-in. radius, the critical range was shifted to temperatures above −50 C. so that all except the room temperature values were low.

Summary of the Charpy Method:

In the simple beam (Charpy) test it is evident that the critical transition range was shifted to higher temperatures by increase of striking velocity, decrease of initial energy, and decrease of notch radius. Beyond a critical value, notch depth had little influence on the transition temperature, and when it was 0.139 in. or greater the absorbed energy was roughly proportional to the broken cross section.

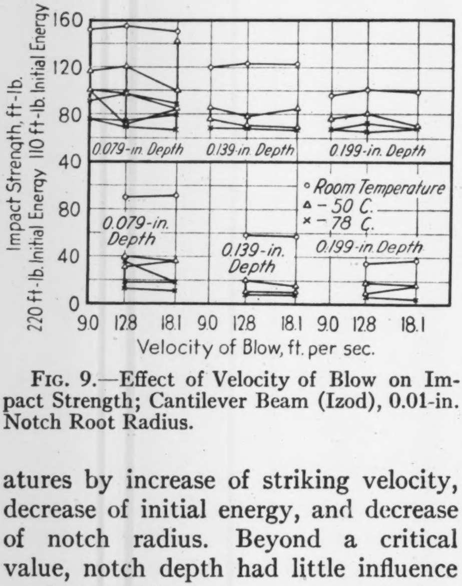

FIG. 9.—Effect of Velocity of Blow on Impact Strength; Cantilever Beam (Izod), 0.01-in. Notch Root Radius.

Samples having the standard Charpy dimensions were also broken on machine B having an initial energy of 223.6 ft-lb., and a striking velocity of 16.9 ft. per sec., with the results shown in Table VI. Under conditions most closely approaching those of the tests in machine A, the initial energies were substantially the same. The differences of velocity, however, were significant as indicated below:

	Machine A (220 ft-lb.)			Machine B (223.6 ft-lb.) Velocity, 16.9 ft. per sec.
	Velocity, 12.8 ft. per sec.	Velocity, 18.1 ft. per sec.	Interpolated Value, Velocity, 16.9 ft. per sec.	
Room temperature	70.0	64.6	65.6	60.1
−50 C.	62.0	26.6	34.5	34.2
−78 C.	40.5	3.4	11.5	8.5

It will be seen that machine B gave results that compare very well with linearly interpolated values of machine A. It may be concluded, therefore, that although the standard Charpy test conditions gave different results on the two machines, the results are comparable when the correction is made for the effect of velocity.

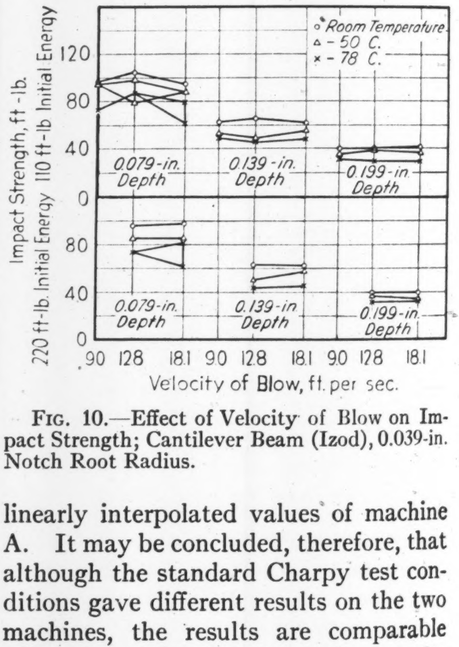

FIG. 10.—Effect of Velocity of Blow on Impact Strength; Cantilever Beam (Izod), 0.039-in. Notch Root Radius.

RESULTS OF CANTILEVER BEAM TEST (IZOD METHOD)

Unlike the results obtained in the tests of the simple beam type, (Charpy) the impact strength as measured in the cantilever type test (Izod) (Figs. 9 and

10), was quite unaffected by variations in the velocity of the impact blow. This was true at all temperatures, initial energies, and notch depths and root radii.

As in the case of the velocity factor, the cantilever (Izod) test was comparatively insensitive to changes in initial energy. Figure 11 clearly shows this to be the case. No significant changes accompanied an increase in the initial energy from 110 to 220 ft-lb. An examination of data, however, showed that there was a tendency to a reduced spread of values for any given set of conditions with higher initial energy.

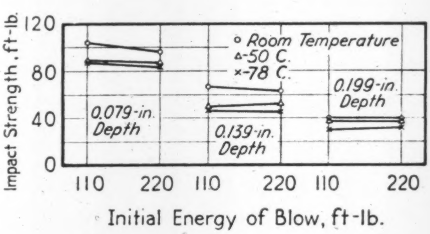

FIG. 11.—Effect of Initial Energy of Blow on Impact Strength; Cantilever Beam (Izod), 0.039-in. Notch Root Radius, 12.8 ft. per sec. Velocity of Blow.

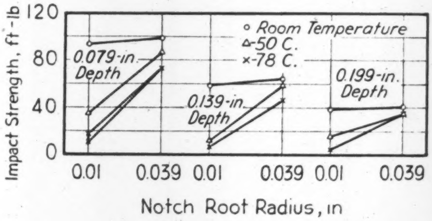

FIG. 12.—Effect of Notch Root Radius on Impact Strength; Cantilever Beam, 18.1 ft. per sec. Velocity of Blow, 220 ft-lb. Initial Energy.

The effect of varying the notch depth was to lower the impact strength with greater depth. As shown in Fig. 11, however, the decrease in impact strength was greater than the proportional decrease in the cross-section broken. The critical range of transition from tough to brittle fracture was unaffected by the notch depth.

Variations in the notch radius had little effect on high values, only a small increase resulting from a change from 0.01 to 0.039 in. (Fig. 12). However, intermediate and low values were increased materially so that in these tests no extremely low values resulted with the 0.039-in. radius notch. That is, the transition range was shifted to temperatures below −78 C.

Length of Cantilever Beam:

For one reason or another, but usually due to wear or breakage of the striking edge, the distance between the top of the vise and the point of impact may vary appreciably in the Izod test. For convenience, this factor was investigated on Izod machine C with the striking edge at the normal distance of 0.866 in. as well as at points 0.081 in. too long and 0.051 in. too short. The average results of the tests above mentioned are given in Fig. 13 and clearly indicate that the length of the cantilever beam has a very material influence on the impact values. As the distance was increased, the high values at room temperature decreased and the intermediate values at low temperature became higher.

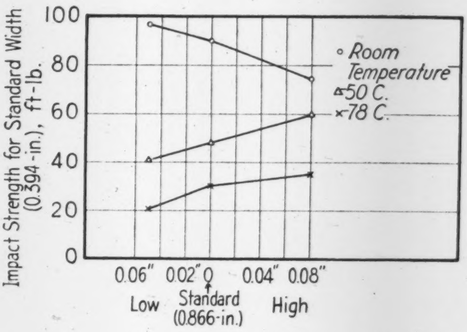

FIG. 13.—Effect of Length of Cantilever Beam. (Machine C).

The smaller amount of energy required for bending with the longer radius is typical of what would be expected in static bending. If a wholly brittle fracture were obtained at the low temperatures, a similar decrease in absorbed energy might be also anticipated at very low values. Inasmuch as a larger amount of energy was absorbed as the beam length increased, it would appear that in intermediate ranges the greater length tends to change the fracture from a brittle to a tough type rather than to give the lower impact value that might be anticipated from geometrical considerations.

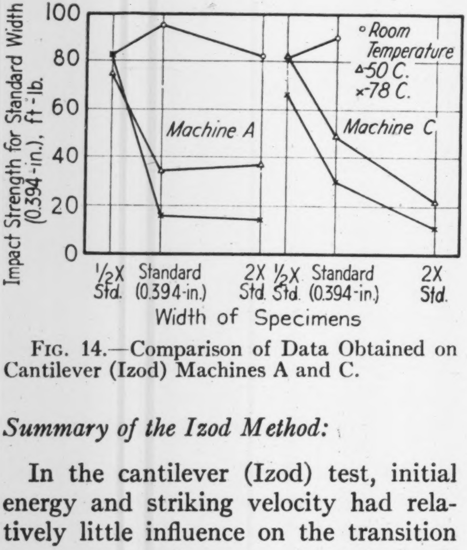

FIG. 14.—Comparison of Data Obtained on Cantilever (Izod) Machines A and C.

Summary of the Izod Method:

In the cantilever (Izod) test, initial energy and striking velocity had relatively little influence on the transition temperature. Increase of notch depth tended to raise the transition temperature somewhat, and increase of notch radius lowered the transition temperature strongly. A high initial energy appeared to be helpful in getting consistent results. The length of the cantilever beam was found to be quite critical and must be maintained accurately to obtain reliable values.

A comparison of the results of Izod tests made on machines A and C is illustrated in Fig. 14. It will be seen that the specimens of standard dimensions gave appreciably different results at low temperatures. However the trend was reversed when the specimen size was doubled. It is evident that there are differences of a secondary order that have not been explained, although in general the two machines gave results that were quite similar.

CONCLUSIONS

The tests described above have been limited to one steel with one heat treatment and have been carried out on only three machines in a narrow temperature range. To that extent the data and therefore the conclusions are limited, but it is believed that qualitative generalizations are justified by the results. It is, therefore, concluded:

1. That in both Charpy and Izod types the machines of different manufacturers can be calibrated or the data adjusted to give comparable values.

2. That the simple beam (Charpy) results are affected by the initial energy and velocity so that correction of the results would be necessary for comparison of the data from machines in which these factors differ. The results are relatively insensitive to depth of notch, and the radius of the standard specimen is large enough to facilitate accurate machining. Comparable results between different Charpy machines, therefore, depend primarily on the original design rather than on maintenance in good condition and accurate specimen preparation.

3. That the cantilever beam (Izod) results are unaffected by initial energy and velocity but are influenced strongly by length of the cantilever arm. The results are also relatively sensitive to notch depth and radius. The accuracy of the Izod type machine appears to depend less on original design and more on careful maintenance of machine di-

mensions and on accurate specimen preparation.

4. That general agreement may be anticipated between different machines of the same type but that imposition of an arbitrary minimum impact strength in specifications is not justified unless the testing temperature and minimum value are not severe or unless the conditions of the test are defined in much more detail than is customary at present.

It is furthermore evident that velocity as such has little if any effect on the results as long as the notch is sufficiently deep and sharp, and the specimen of such a size that stress "concentration" can be realized. This has also been confirmed by static tests in notched specimens in which the change from tough to brittle types of fracture could be induced by increasing the concentration of stresses under the notch. The observation that a brittle fracture may result solely from concentration of complex stresses carries the implication that the notch need not be present provided the section is sufficiently heavy to develop an appreciable stress in a direction normal to the surface. Thus, the conclusion may also be reached from these tests that the notched-bar impact test is a suitable criterion for estimating the resistance to brittle failure of unnotched sections under static load.

DISCUSSION

MR. J. M. LESSELLS[1] (*presented in written form*).—This paper is of interest in the further interpretation of the impact test. In Figs. 2 and 3, the transitions from the ductile fracture to the brittle type of fracture, so well explained by the German workers[2], are clearly shown. Although it is mentioned by the authors, it might be advisable to emphasize the fact that such fractures are entirely different, one being a ductile failure with large deformation, the other being a brittle fracture with little or no deformation. Engineers call them sliding and separation failures, respectively, as did Moser. Regarding the remarks on p. 671, engineers, I believe, consider that in the case of sudden failure of large forgings, where no deformation is possible and where three-dimensional stress may exist, the characteristic separation failure will result. This can also be shown experimentally by simple tension tests on notched bars[3]. If the width of the notch be sufficiently great, the normal shearing type of failure will result, but if the width of the notch is decreased, a stage will be reached at which the separation type of failure will result, due to the suppression of lateral contraction.

It is agreeable to note that the authors are of the opinion that there is no great difference between the Charpy and Izod types. This serves to explain why these two types are more or less standard in European laboratories today.

MR. M. F. SAYRE[4] (*by letter*).—This paper represents a very valuable and painstaking experimental survey of the effect of a range of variations in conditions upon impact results by the Charpy and Izod methods. A difficulty in commenting upon it arises from the fact that so much information has been presented that it takes a good deal of time really to digest it.

One definite conclusion, however, to which these results seem to point is that a knowledge of numerical value of impact strength obtained in any single test is of much less importance than a knowledge of the change of conditions needed to produce a brittle fracture. This leads, for example, to the statement that a series of carefully made reproducible tests, on specimens of standardized size, all at room temperatures, may tell very much less about the properties of a material than a similar series, possibly less carefully made, covering a range of sizes of specimens or a range of temperatures, or both. This will be particularly true if some of the specimens in this second series show brittle and others ductile behavior. Specimens which happen to lie in the transition range between ductile and brittle behavior will of course not show reproducible results numerically in successive tests, yet may nevertheless give valuable information. Thus the very fact that the series of test results for Izod specimens with notch root radius of 0.039 in. in Table V are so delightfully consistent may be very good reason for refusing to use this type of specimen on acceptance tests for this material.

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[1] Associate Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

[2] Max Moser, "Notched Bar Tests," *Transactions*, Am. Soc. Mechanical Engrs., A.P.M. 55-141, Figs. 4 and 5 (1933).

[3] S. Timoshenko, "Strength of Materials," Part II (Second Printing), p. 674, D. Van Nostrand Co., New York City (1934).

[4] Professor of Applied Mechanics, Union College, Schenectady, N. Y.

The form of the notch and the temperature used in testing should be so chosen as to insure, in so far as feasible, that material of a satisfactory character will break with ductile behavior, yet a slight drop in quality will cause a brittle break. Standardization on the same type of specimen for all materials may turn out to be highly unwise. Failure to recognize this fact is a major reason why in the past, our results with the impact test have often appeared to be unsatisfactory.

A couple of minor points: (1) In specimens which broke in ductile fashion, the impact energy value in these tables seem to vary more nearly as the square of the depth below the notch than as the first power. (2) Comparison between Table III and Tables IV and V is prevented because the initial energy and velocity of blow for the tests of Table III do not seem to be given. This additional information would be advantageous for further study of the results.

MESSRS. WALTER CRAFTS[5] AND JOHN J. EGAN[5] (*authors' closure by letter*).—The reference by Mr. Lessells to the broader significance of the notched-bar impact test as a criterion of ductility under three-dimensional stress is completely in concurrence with the authors' opinion. As indicated on page 671, it is believed that the notch and dynamic loading act to produce in a small specimen the same type of stresses that occur under static loading in an unnotched larger specimen, for example the plate of a pressure vessel. Obviously, as the stress normal to the surface of a plate is increased by increase in thickness of the plate, the need of resistance to three-dimensional stress and therefore of notched bar toughness, increases. For this reason there can be no fixed criterion of adequate toughness, and logical choice between Izod or Charpy test must depend on relative sensitivity within the required range and adaptability to the use of larger and smaller than standard specimens.

Mr. Sayre's suggestion that the impact test should be so carried out as to define the degree of toughness is worthy of careful consideration. In addition to the variables described in the paper, the effect of width should also be included among the factors that can be varied to determine to what degree a "tough" steel can be submitted to severe loading conditions. The accurate determination of the test condition under which the fracture changes from "tough" to "brittle" implies a knowledge that the test is comparable to the service. In order to utilize the test properly, therefore, and in fact, in order to be assured of freedom from brittle failure, a more or less accurate correlation between the service and the test must be established.

In regard to the increase of absorbed energy with the depth below the notch, no tests have been made to establish the true relationship. It is felt that, although the shape of the curve showing its relation between absorbed energy and cross-section of metal appears to be parabolic, above a certain critical notch depth the curve inclines to be linear. As the notch depth is decreased the volume of deformed metal increases greatly and, in effect, the notch radius increases to a very high value. The absorbed energy, therefore, increases sharply, but this is believed to be due to factors other than the increase in depth below the notch. The tests in Table III were made with initial energies of 110 ft-lb. for the Izod and 220 ft-lb. for the Charpy tests, and striking velocities of 12.8 ft-lb. for the Izod and 18.1 ft-lb. for the Charpy tests.

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[5] Research Metallurgists, Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y.

ATMOSPHERIC CORROSION OF NON-FERROUS METALS AND ALLOYS

By Carl W. Borgmann[1]

Synopsis

The results reported by Subcommittee VI on Atmospheric Corrosion of the Society's Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys covering the first three test periods (1, 3, and 6 yr.) have been critically reviewed. The results of the weight-change measurements and the descriptions of the visual appearance were found to be of little use in forming a judgment regarding the relative corrosion resistance of the test materials. However, the results of the tests on change in tensile strength and percentage elongation are considered to be of considerable importance to the engineering profession. The limitations in any attempt to evaluate the results in terms of corrosion resistance at this time are thoroughly discussed. However, a rough division of the materials into three classes is made, subject, of course, to the previously mentioned limitations.

The work of Subcommittee VI of the Society's Committee B-3 has now progressed for more than 12 yr. More than 7 yr. of exposure have been completed and the results of three periods (approximately 1, 3 and 6 yr.) have been published.[2, 3, 4] An interpretation of the 1-yr. results has been made by Finkeldey.[5] The author has been invited to review these results and to draw whatever conclusions that seem justified at this time with the results of five more years exposure available. All statements made are the opinions of the author and in no way represent the official action of Committee B-3.

The materials under test, the test locations, the method of mounting specimens and other details are adequately described in an early report by the committee.[6] In Table I (included for convenience) are given the twenty-four materials under test and the nine test locations. Measurements of change in weight of 9 by 12-in. plates were made on each material. Also, six standard tension specimens were tested from each material and location at each period of exposure. The data accumulated are voluminous and are vastly important. However, the remarks made in this paper must be taken simply as the trend after 6 yr. Modifications will undoubtedly be necessary as further results are forthcoming.

Weight Change Measurements:

For purposes of quantitative interpretation, the results of the weight change measurements are useless.[7] Even for a qualitative treatment, the results are difficult to interpret. Loss of weight must be due to loss of corrosion product from the metal through solution or erosion to such an extent that the remaining metal and any surface deposit weigh less than the original metal.[8] It is to be noted that the aluminum alloys, with few exceptions, show gains in weight. The copper alloys tend to give losses of weight in industrial atmospheres (except Rochester) and gains in seacoast atmospheres. The nickel-copper alloy (S), nickel, lead, and zinc show losses of weight almost universally at the end of 6 yr., whereas, tin shows an increase of weight in every location. Undoubtedly, the solubility of the corrosion products on zinc, and nickel, and to a less extent on copper, in the dilute acid formed by rain is an important factor influencing the losses shown by these metals and alloys in industrial atmospheres.[9] Erosion must play the major role in the case of lead. The corrosion products on metals at the seacoast locations are in atmospheres relatively free of acidic gases, and hence, erosion probably accounts for any losses met in such environments.

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[1] Head of Department of Chemical Engineering, University of Colorado, Boulder, Colo.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part I, p. 234 (1933).

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part I, p. 142 (1935).

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 194 (1938).

[5] W. H. Finkeldey, "The Early Interpretation of Test Results in the Atmospheric Corrosion of Non-Ferrous Metals and Alloys," Symposium on Outdoor Weathering of Metals and Metallic Coatings, p. 69, Washington Regional Meeting, Am. Soc. Testing Mats. (1934). (Available as separate publication.)

[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part I p. 214 (1932).

TABLE I.—A.S.T.M. ATMOSPHERIC CORROSION TEST ON NON-FERROUS METALS.

Material	Composition
Copper and Copper Alloys:	
A	Cu, 99.9+; O, 0.036
B	Cu, 99.9+; P, 0.007
C	Cu, 96; Si, 3; Mn, 1
D	Cu, 92; Sn, 8
F	Cu, 92; Al, 8
K	Cu, 66.4; Zn, 19.3 Al, 5.9; Fe, 4.6; Mn, 3.8
L	Cu, 85; Zn, 15
M	Cu, 70; Zn, 30
N	Cu, 70; Zn, 29; Sn, 1
P	Cu, 75; Ni, 20; Zn, 5
Q	Cu, 70; Ni, 29; Sn, 1
Aluminum and Aluminum Alloys:	
G	Al, 99+
I	Al, 99; Mn, 1
O	Al, 95; Cu, 4; Mn, 0.5 Mg, 0.5
Z	Al, 98; Mg, 0.5; Si, 1
FF	Aluminum-coated Duralumin (alloy O)
Nickel and Nickel Alloy:	
S	Ni, 65; Cu, 32; Fe, 2 Mn, 1
T	Ni, 99+
Lead and Tin:	
U	Pb, 99.92; Cu, 0.06
CC	Pb, 99; Sb, 1
EE	Sn, 99.85+
Zinc:	
AA	Zn, 99; Pb, 0.85
BB	Zn, 99.9+
HH	Zn, 99.99+

Location	Test Location	Type[a]
No. 1	Pittsburgh, Pa.	Industrial
No. 2	Altoona, Pa.	
No. 4	New York City	
No. 6	Rochester, N. Y.	
No. 5	Sandy Hook, N. J.	Seacoast
No. 7	Key West, Fla.	
No. 9	La Jolla, Calif.	
No. 3	State College, Pa.	Rural
No. 8	Phoenix, Ariz.	

[a] See *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 200 (1938) for complete summary of meteorological data.

Unless the techniques developed by Vernon[10] and Hudson[11] are followed, and that is quite impossible in the present case, change in weight measurements of

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[7] A summary of weight loss results is given in *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 202-213 (1938).

[8] An excellent discussion of weight change results is given by W. H. Finkeldey, *Ibid.*, pp. 72-78. See also the discussion by J. C. Hudson of this paper, p. 93.

[9] See discussion by J. C. Hudson of Finkeldey paper, p. 93.

[10] W. H. J. Vernon, "Second Report to British Non-Ferrous Metals Research Association," *Transactions*, Faraday Soc., Vol. 23, p. 113 (1927).

[11] J. C. Hudson, "Third Report to British Non-Ferrous Metals Research Association," *Transactions*, Faraday Soc., Vol. 25, p. 178 (1929).

TABLE II.—AVERAGE TENSILE STRENGTH OF ALLOYS (psi. × 10^{-3}) AFTER 6 YR. CORROSION.

Alloy	Pittsburgh, Pa. 1		Altoona, Pa. 2		New York City 4		Rochester, N. Y. 6		Sandy Hook, N. J. 5		Key West, Fla. 7		La Jolla, Calif. 9		State College, Pa. 3		Phoenix, Ariz. 8		Storage 10		Initial[a] 11	
	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.	$\bar{x}$	σ'est.
A	32.2	(0.20)	31.9	(0.13)	32.4	(0.23)	32.7	(0.18)	32.8	(0.18)	33.6	(0.44)	31.7	(0.31)	32.8	(0.17)	33.3	(0.32)	33.6	(0.06)	35.2	(0.58)
B	34.4	(0.15)	34.4	(0.48)	34.0	(0.24)	34.6	(0.14)	34.4	(0.32)	35.0	(0.37)	33.6	(0.20)	35.0	(0.11)	35.7	(0.16)	35.5	(0.21)	35.2	(0.25)
C	56.2	(0.70)	53.2	(3.87)	56.5	(2.32)	57.2	(0.22)	56.3	(0.90)	57.8	(0.46)	55.8	(0.98)	58.4	(0.34)	59.0	(0.68)	59.5	(0.97)	59.1	(0.72)
D	55.4	(0.35)	55.2	(1.20)	55.4	(1.33)	57.5	(1.14)	56.7	(0.37)	57.3	(0.61)	54.8	(0.83)	57.0	(0.80)	58.2	(1.21)	56.8	(0.53)	58.9	(0.86)
F	70.9	(1.61)	71.5	(0.52)	71.7	(1.49)	74.3	(1.73)	73.1	(2.96)	75.1	(2.76)	84.5	(5.47)	74.5	(0.83)	82.4	(1.22)	77.4[b] 83.9[d]	(0.89) (0.99)	74.1[c] 82.9[d]	(0.77) (1.18)
K	86.9	(3.96)	86.6	(10.67)	78.5	(4.27)	103	(3.2)	96.7	(1.57)	104	(2.2)	84.2	(6.34)	119	(6.0)	117	(5.7)	124	(3.4)	122	(4.6)
L	37.6	(0.67)	38.1	(0.42)	38.2	(0.62)	39.7	(0.46)	39.7	(0.32)	40.6	(0.37)	40.1	(0.37)	40.4	(0.46)	41.2	(0.49)	40.9	(0.74)	39.9	(0.35)
M	41.8	(0.68)	40.1	(0.28)	39.7	(0.57)	46.7	(0.53)	44.8	(0.62)	47.8	(0.75)	46.4	(0.37)	47.5	(0.49)	48.4	(0.74)	48.3	(0.78)	48.1	(0.37)
N	50.7	(0.40)	51.5	(0.33)	51.1	(0.36)	52.3	(0.26)	51.8	(0.35)	53.2	(0.13)	53.3	(0.33)	53.2	(0.52)	53.8	(0.37)	54.1	(0.34)	55.0	(0.34)
P	50.3	(0.15)	50.5	(0.28)	50.0	(1.11)	51.0	(0.61)	52.0	(0.25)	52.1	(0.32)	52.9	(0.46)	52.8	(0.60)	53.0	(0.67)	53.1	(0.49)	54.3	(0.38)
Q	73.9	(4.95)	74.1	(4.48)	76.7	(2.30)	75.7	(4.26)	75.5	(4.75)	72.8	(1.02)	76.3	(3.83)	80.0	(6.19)	78.5	(5.89)	78.3	(4.98)	76.7[e]	(4.10)
G	16.0	(0.24)	15.9	(0.13)	15.9	(0.08)	16.5	(0.39)	16.2	(0.24)	16.4	(0.23)	13.5	(0.87)	16.6	(0.41)	16.6	(0.22)	16.7	(0.06)	16.4	(0.09)
I	19.5	(0.19)	19.0	(0.13)	19.6	(0.35)	20.3	(0.18)	20.1	(0.22)	20.4	(0.13)	19.2	(0.36)	20.3	(0.10)	20.0	(0.29)	20.4	(0.10)	20.5	(0.21)
O	60.6	(1.58)	60.0	(1.07)	58.6	(0.90)	62.8	(0.56)	61.0	(0.35)	63.7	(1.04)	40.7	(2.75)	65.1	(0.92)	65.4	(1.28)	65.2	(0.35)	63.7	(0.62)
Z	38.5	(0.74)	36.9	(1.14)	37.5	(1.29)	39.8	(0.53)	38.0	(1.02)	41.0	(0.86)	30.2	(2.07)	41.3	(0.64)	43.3	(0.32)	42.2	(0.28)	38.0	(0.58)
FF	58.8	(0.76)	59.0	(0.56)	59.3	(0.80)	58.4[j]	(0.86)	59.0	(1.05)	59.9	(0.86)	59.6	(0.55)	59.5	(0.95)	59.1	(1.10)	59.5	(0.91)	58.8	(0.71)
S	78.7	(1.17)	77.7	(0.62)	76.8	(0.88)	78.8	(1.11)	78.0	(0.33)	79.0	(0.67)	79.2	(1.13)	79.0	(0.75)	79.1	(0.54)	79.1	(0.42)	79.4[e]	(1.34)
T	68.7	(0.47)	67.3	(0.53)	67.6	(0.66)	71.5	(0.61)	72.0	(0.40)	72.9	(0.39)	72.9	(0.48)	73.7	(0.44)	72.8	(0.33)	73.0	(0.67)	71.1[e]	(0.53)
U[g]	23.7	(0.02)	23.4	(0.12)	23.8	(0.23)	23.7[f]	(0.20)	23.7	(0.26)	23.6	(0.25)	23.9	(0.17)	23.8	(0.27)	24.0	(0.22)	23.0	(0.29)	25.8	(0.58)
CC[g]	31.0	(0.17)	30.6	(0.26)	31.3	(0.29)	30.8	(0.33)	31.2	(0.32)	30.9	(0.30)	30.8	(0.31)	31.4	(0.35)	30.2	(0.35)	31.5	(0.45)	34.8	(0.78)
EE[g]	30.4	(1.27)	29.4	(0.86)	30.6	(0.80)	31.5	(0.49)	29.5	(0.92)	30.0	(0.51)	27.9	(0.81)	31.6	(0.72)	30.0	(0.28)	34.5	(0.49)	37.6	(1.49)
AA	25.7	(0.17)	24.9	(0.13)	25.5	(0.16)	27.7[h]	(0. 7)	27.6	(0.11)	28.5	(0.18)	23.6[i]		27.8	(0.03)	28.6	(0.13)	29.4	(0.10)	29.9	(0.31)
BB	16.6	(0.02)	15.9	(0.17)	16.5	(0.02)	17.4[f]	(0)	17.4	(0.02)	17.8	(0.13)	16.3	(0.42)	18.0	(0.15)	18.1	(0.02)	18.8	(0.17)	18.3	(0.16)
HH	16.4	(0.37)	16.1	(0.24)	16.6	(0.25)	18.1	(0.28)	18.2	(0.16)	18.7	(0.16)	16.4	(1.18)	18.3	(0.30)	18.7	(0.26)	19.1	(0.23)	18.8	(0.48)

[a] Initial results are average of twelve tests unless otherwise noted.
[b] Value to be used with results from stations 1 to 7 inclusive, average of four specimens.
[c] Value to be used with results from stations 1 to 7 inclusive, average of ten specimens.
[d] Value to be used with results from stations 8 and 9.
[e] Average of eleven specimens.
[f] Average of five specimens.
[g] Results are in psi. × 10^{-2}.
[h] Average of four specimens.
[i] Only one specimen. Other five broke in grips.

atmospheric corrosion can never have a quantitative meaning. The corrosion of a few metals such as zinc, and possibly nickel, in strongly industrial atmospheres can be followed in a semi-quantitative manner by simple weight loss measurements as the amount of corrosion product clinging to the surface is slight.[12]

TABLE III.—PERCENTAGE CHANGE IN TENSILE STRENGTH IN 6 YR. (BASED ON STORAGE SPECIMENS).[a]

Material	Pittsburgh, Pa. 1	Altoona, Pa. 2	New York City 4	Rochester, N. Y. 6	Sandy Hook, N. J. 5	Key West, Fla. 7	La Jolla, Calif. 9	State College, Pa. 3	Phoenix, Ariz. 8	Initial
A	−4	−5	−4	−3	−2	(0)	−6	−2	(−1)	+5
B	−3	−3	−4	−3	−3	(−1)	−5	−1	(+1)	(−1)
C	−6	−11	(−5)	−4	−5	−3	−6	(−2)	(−1)	(−1)
D	−3	(−3)	(−3)	(+1)	(0)	(+1)	−4	(0)	(+3)	+4
F	−8	−8	−7	(−4)	(−6)	(−3)	(+1)	−4	(−2)	-4^b; $(-1)^c$
K	−30	−30	−37	−17	−23	−16	−32	(−4)	(−6)	(−1)
L	−8	−7	−7	−3	−3	(−1)	(−2)	(−1)	(+1)	−2
M	−14	−17	−18	−3	−7	(−1)	−4	(−2)	(0)	(−1)
N	−6	−5	−6	−3	−4	−2	−2	−2	(−1)	+2
P	−6	−5	−6	−4	−2	−2	(−1)	(−1)	(0)	+2
Q	(−6)	(−5)	(−2)	(−3)	(−4)	(−7)	(−3)	(+2)	(0)	(−2)
G	−4	−5	−5	(−1)	−3	(−2)	−19	(−1)	(−1)	−2
I	−4	−7	−4	(0)	(−2)	(0)	−6	(−1)	(−2)	(0)
O	−7	−8	−10	−4	−6	−2	−38	(0)	(0)	−2
Z	−9	−13	−11	−6	−10	−3	−28	−2	+3	−10
FF	(−1)	(−1)	(0)	(−2)	(−1)	(+1)	(0)	(0)	(−1)	(−1)
S	(−1)	−2	−3	(0)	−1	(0)	(0)	(0)	(0)	(0)
T	−6	−8	−7	−2	(−1)	(0)	(0)	(+1)	(0)	−4
U	+3	(+2)	+3	+3	+3	+3	+4	+3	+4	+11
CC	(−2)	−3	(−1)	(−2)	(−1)	(−2)	−2	(0)	−4	+10
EE	−12	−15	−11	−9	−15	−13	−19	−8	−13	+9
AA	−13	−15	−13	−6	−6	−3	−20	−5	−3	+2
BB	−12	−15	−12	−7	−7	−5	−13	−4	−4	−3
HH	−14	−16	−13	−5	−5	−2	−14	−4	−2	(−2)

[a] The results in parentheses are not significant at $p = 0.01$.
[b] Value for use with results from stations 1 to 7.
[c] Value for use with results from stations 8 and 9.

Change in Tensile Strength:

The change in tensile strength are the most important results gained from the investigation and the committee is to be complimented in making them available to the engineering profession. The only conclusions drawn by the author are based on these results. The original test data for the initial tests and the 6-yr. tests have been completely analyzed by the author. The study of the results has brought out certain technical details of calculation that require comment. The data on which the tensile strengths have been calculated (the cross-section of the specimen and the load) are, at best, only good to three significant figures. Hence, all other figures in the published tensile strengths should be rounded off and a uniform procedure adopted in future publications. Secondly, it would have been valuable to have published the standard deviations for each averaged result.[13] The estimated standard deviation has been calculated for the 6-yr. results according to the following formula[14] and is given in Table II:

$$\sigma' \text{ est.} = \sqrt{\frac{\Sigma (x - \bar{x})^2}{n - 1}}$$

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[12] See discussion by J. C. Hudson of Finkeldey paper, p. 93.

[13] Manual on Presentation of Data, sponsored by Committee E-1 on Methods of Testing, *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part I, p. 453 (1933). (Also available as separate publication.)

[14] R. A. Fisher, "Statistical Methods for Research Workers," Sixth Edition, p. 47, Oliver & Boyd, Edinburgh and London (1936).

The above formula gives a somewhat more conservative estimate of the standard deviation of small samples than the one suggested in the A.S.T.M. Manual.[13] If the sample size n is 6, it is only necessary to multiply the values given in Table II by 0.912 in order to estimate the standard deviation as calculated by the formula in the A.S.T.M. Manual. As a test for significance, Subcommittee VI uses a formula[3] to calculate the "maximum percentage difference due to chance." The author felt that an alternative test for significance might be valuable, particularly as a check on the formula employed by the subcommittee. Hence, Student's "*t*-test"[15] for the significance of the difference of means was applied to compare the mean of the storage tests with that of the 6-yr. exposure tests (see Table III). Using a 0.01 level of probability of significance, there are 13 out of a possible 216 comparisons where the method employed by the author does not agree with that of the subcommittee. However, 11 of the 13 cases are readily accounted for by the slight difference in significance level between the two methods. The other 2 cases, namely, for material F at Rochester and Sandy Hook, represent quite real differences for which no explanation has been found. On the whole there is excellent agreement between the two methods of judging significance, and it is suggested that the formula used previously by Subcommittee VI is quite satisfactory for future use. And finally, several typographical errors in the tables of published data were found. These should be carefully checked before further publication.

It has been difficult to find a criterion suitable for interpretation of the results. The important result is the percentage change of tensile strength. An estimation of this value gives but one result for each metal at each location and for each period of exposure—rather than six. However, if we assume these single values to represent our best estimate of corrosion damage, a modification of Student's "*t*-test"[16] is applicable. An alternative, and more exact, method can be applied for comparing the different environments. The tensile strength measurements themselves can be used for this purpose—a comparison being made between the average strength of all alloys under consideration in one location and that strength in the other. The two methods check each other reasonably well and give support to the use of the first method, which is the only one applicable to comparison of metals. The following statements are made from a statistical study of the 6-yr. results using the above tests for significance.

Comparison of Atmospheres.—Using the mean results from all twenty-four alloys as an estimation of the severity of corrosion, one finds that there is no significant difference between the atmospheres classed as industrial and those classed as seacoast. The seacoast and industrial atmospheres are more corrosive than rural. Among the industrial type of atmospheres, those at Altoona, Pittsburgh, and New York are quite similar in behavior and are all much more corrosive than the atmosphere at Rochester. La Jolla is the most corrosive of the seacoast locations, Sandy Hook, second, and Key West, least. The rural atmospheres are not significantly different in behavior at this time, although, as one would expect, Phoenix tends to be the least corrosive of all. Both Rochester and Key West are more corrosive than State College.

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[15] R. A. Fisher, *Ibid.*, p. 128.

[16] R. A. Fisher, *Ibid.*, p. 126.

The most important factor in the corrosiveness of "inland" atmospheres is undoubtedly the sulfur dioxide pollution. The other meteorological factors[17, 18] apparently play but a minor role. It is difficult to judge the most important factor in the seacoast locations. Certainly, the averaged meteorological data, such as temperature rainfall, humidity, etc., are no criteria. Small differences in the physical location of the racks apparently have the greatest influence. The test rack at La Jolla is located at the edge of a rocky shore, and, consequently, the metals must be in an almost perpetual sea-water spray. The coast at Sandy Hook and Key West is sandy and the racks are at least one hundred yards away from the sea. Hence, sea spray will only reach the specimens in appreciable amounts during violent storms. One would hazard the guess that points along the New England coast might approach the corrosiveness of La Jolla.

TABLE IV.—THE INFLUENCE OF TIME ON THE PERCENTAGE LOSS IN TENSILE STRENGTH.

Material	Length of Exposure, yr.	Pittsburgh, Pa. 1	Altoona, Pa. 2	New York City 4	Rochester, N. Y. 6	Sandy Hook, N. J. 5	Key West, Fla. 7	La Jolla, Calif. 9	State College, Pa. 3	Phoenix, Ariz. 8
K........	1	−3	−8	−4	−1	+10	+3	−19	+2	+3
	3	−13	−17	−21	+5	−7	−7	−28	−5	−9
	6	−30	−30	−37	−17	−23	−16	−32	−4	−6
M........	1	−3	−2	−5	0	−2	0	−4	−1	+1
	3	−10	−9	−12	−3	−4	−1	−4	0	−1
	6	−14	−17	−18	−3	−7	−1	−4	−2	0
O........	1	−4	−10	−9	−3	−10	−4	−35	+1	−1
	3	−7	−8	−8	−4	−9	−4	−33	−2	0
	6	−7	−8	−10	−4	−6	−2	−38	0	0
Z........	1	−3	−6	−6	−1	−3	−1	−20	−1	+2
	3	−6	−8	−8	−1	−5	−1	−24	−3	+5
	6	−9	−13	−11	−6	−10	−3	−28	−2	+3
BB.......	1	−3	−2	−2	−1	−1	+1	−4	−1	+1
	3	−4	−4	−5	−1	−1	0	−6	−2	+1
	6	−12	−15	−12	−7	−7	−5	−13	−4	−4

Copper Alloys.—The copper alloys as a group show excellent resistance to atmospheric corrosion. They are somewhat more corroded by industrial than by seacoast atmospheres, possibly excepting that at La Jolla. Alloy K (manganese bronze), however, shows outstandingly poor corrosion resistance as well as having highly variable physical properties initially. Table IV indicates that the loss in tensile strength of this alloy is becoming greater with time. An interesting comparison can be made between alloys L (85 per cent brass) and M (70 per cent brass). The former is significantly better than the latter, indicating the value of high-copper brasses for outdoor use. Alloy N (70 per cent copper, 29 per cent zinc, 1 per cent tin) compares closely in composition with alloy M (different only in tin). However, alloy N, while not significantly better than M at this time, will probably prove the better alloy after the next exposure period. There appears to be little to choose between the other alloys.

Aluminum Alloys.—Alloy I (1 per

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[17] G. N. Schramm and E. S. Taylerson, "The Influence of Rainfall and Smoke on the Corrosion of Iron and Steel," Symposium on the Outdoor Weathering of Metals and Metallic Coatings, p. 62, Washington Regional Meeting, Am. Soc. Testing Mats. (1934). (Available as separate publication.)

[18] Discussion by R. F. Passano, W. H. J. Vernon and J. C. Hudson of paper by Schramm and Taylerson, *Ibid* pp. 63–68.

cent manganese) appears to be the best of the uncoated aluminum alloys from the standpoint of change in tensile strength. However, it is no better than alloy G (commercial aluminum) in all atmospheres except La Jolla. Both show good resistance as judged by change in tensile strength. The strong alloys, O (duralumin) and Z (1 per cent silicon, 0.5 per cent magnesium), are somewhat more susceptible to corrosion. The losses of tensile strength at La Jolla are excessive. However, as pointed out by Dix,[19] the percentage losses are materially influenced by the thickness of specimen and little further change occurs after a period of 1 yr. His observations are confirmed by the present results. The change in tensile strength (particularly of alloy O) was most marked after 1 yr. and further changes have been small (see Table IV). The alloy FF (aluminum-coated duralumin) is withstanding corrosion, as judged by loss in tensile strength, perfectly.

Nickel and Nickel-Copper Alloy.—Both materials, and particularly alloy S (nickel-copper), show excellent resistance to corrosion in all atmospheres Alloy T (commercial nickel) is somewhat affected by industrial atmospheres.

Lead, Lead-Antimony, Tin.—The results of alloy U (commercial lead) need an explanation. This alloy, as compared with storage results, has gained strength to a significant extent in practically all locations. However, in comparison with the initial tests, appreciable losses are to be noted. Possibly the exposed specimens were cold worked slightly. Certainly, an appreciable amount of creep must have occurred considering the distance between supports. The stronger alloy CC (lead-antimony) does not show the foregoing anomaly. Good corrosion resistance is shown by this alloy. Alloy EE (commercial tin) shows surprisingly high loss in strength, even at Phoenix. The high loss is probably explained by the fact that the attack was localized (pitting) in almost every case.

Zinc.—The three zincs (alloys AA, BB and HH) all behave similarly and are corroded most severely by the seacoast atmosphere of La Jolla and the three strongly industrial atmospheres. There is no significant difference among these three alloys. The amount of damage has increased steadily with time, as indicated in Table IV.

Changes in Percentage Elongation:

The changes in elongation parallel the changes in tensile strength in general. However, it should be noted that the metallic property measured by a determination of the percentage elongation over a definite gage length is vague, to say the least. The large number of cases of apparently significant gains in elongation and the very general condition of large variation between measurements on the same material lead one to have a certain skepticism about use of the results. Further, the use of specimens machined to shape before exposure will overly emphasize the change in elongation because of the notch effect of pits along the edges. It is also difficult to extrapolate the results of change in elongation to other thicknesses of material. The following discussion is based on a qualitative study of Table V, which gives the percentage change in elongation after 6 yr., as taken from the published reports. The values in parentheses are those less than the "maximum variation due to chance." It was felt that these results did not warrant the treatment given the tensile strength results.

Copper and Copper Alloys.—The copper alloys, with the exception of alloys K (manganese bronze) and M (70 per cent brass), show only small or insignificant changes in elongation. Alloy K has very high losses of elongation in all locations except at State College and Phoenix. Alloy M shows an appreciable loss of elongation in the three severely industrial atmospheres. The influence of the addition of 1 per cent tin (alloy N) is strikingly apparent. The loss in elongation increases with time (see Table VI) for the two alloys discussed (K and M).

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[19] E. H. Dix, Jr.,"Corrosion Resistance of Structural Aluminum," *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 405 (1933). Also see discussion, p. 413.

TABLE V.—PERCENTAGE CHANGE IN ELONGATION AFTER SIX YEARS ATMOSPHERIC CORROSION (BASED ON STORAGE SPECIMENS).[a]

Data Taken Directly from 1938 Committee Report

Material	Pittsburgh, Pa. 1	Altoona, Pa. 2	New York City 4	Rochester, N. Y. 6	Sandy Hook, N. J. 5	Key West, Fla. 7	La Jolla, Calif. 9	State College, Pa. 3	Phoenix, Ariz. 8	Initial
A	(−1)	(+1)	(−2)	(0)	(−2)	(0)	(−2)	(−1)	(−1)	−4
B	(−4)	(−4)	−4	(−2)	(−1)	(+1)	−6	(−1)	−4	−10
C	(−2)	(+1)	(−1)	(+1)	(+1)	(0)	(+1)	(−1)	(−1)	−6
D	(−1)	(0)	(0)	(+1)	(+1)	(+1)	(+1)	(−1)	(+1)	(−1)
F	+4	+4	+3	(−2)	(+2)	−6	(−7)	+5	(+4)	(−1)[b]; (+2)[c]
K	−35	−68	−52	−68	−52	−30	−87	(−3)	(−18)	(+17)
L	(0)	(0)	(0)	(−2)	(+1)	(−2)	(+1)	(0)	(+1)	(0)
M	−12	−19	−17	(−1)	−9	(−1)	(−3)	(0)	(−3)	−14
N	+3	(+2)	+4	(+3)	(+2)	(+2)	+3	(+3)	(0)	(+2)
P	(−1)	(−1)	(−2)	(−1)	(−2)	(+1)	(−1)	(0)	(+1)	(−2)
Q	(+4)	(+4)	(−7)	(+4)	(+8)	+22	(+8)	(−3)	(+2)	+7
G	−11	−20	−24	−16	(−16)	(+1)	−64	(+2)	(+4)	(+16)
I	−18	(−11)	−17	(+7)	(−7)	(+9)	−53	(+7)	(+1)	+6
O	−33	−37	−48	−29	−38	−28	−90	(−6)	(−1)	(+1)
Z	−36	−44	−42	−40	−45	−48	−82	(−10)	−15	(0)
FF	−10	−8	(−1)	(−18)	−4	(−1)	(−2)	(−6)	(+2)	+3
S	(0)	(0)	(+2)	(−2)	(+1)	(0)	(−1)	(+1)	(−1)	(−1)
T	(0)	(−1)	(−1)	(−1)	(+1)	(0)	(−1)	(+1)	−2	−3
U	(+1)	(−1)	(−3)	(−18)	(−3)	(+1)	(−10)	(−4)	(+4)	(+5)
CC	(−1)	−11	−7	−17	(+2)	(−2)	−14	(−6)	(0)	−17
EE	(−1)	(−1)	(−3)	(−5)	−34	(−8)	−67	(+10)	(−5)	(−4)
AA	(−18)	−27	(−10)	−30	(−1)	(−9)	−97	(−5)	(+7)	(−4)
BB	−9	−16	−9	(−4)	−5	(−3)	−45	(+3)	(+1)	(+1)
HH	(−7)	−15	−11	−16	(−7)	−8	−56	(−6)	(−2)	(−4)

[a] The values in parentheses are those less than maximum variation due to chance.
[b] Value for use with results from stations Nos. 1 to 7.
[c] Value for use with results from stations Nos. 8 and 9.

TABLE VI.—THE INFLUENCE OF TIME ON THE PERCENTAGE LOSS IN PER CENT ELONGATION IN 2 IN.

Material	Length of Exposure, yr.	Pittsburgh, Pa. 1	Altoona, Pa. 2	New York City 4	Rochester, N. Y. 6	Sandy Hook, N. J. 5	Key West, Fla. 7	La Jolla, Calif. 9	State College, Pa. 3	Phoenix, Ariz. 8
K	1	−4	+12	−27	−26	−26	−18	−66	..	..
	3	−16	−19	−25	−12	−13	−22	−64	..	..
	6	−35	−68	−52	−68	−52	−30	−87	..	..
M	1	0	+3	−4	..	..	..	..	..	..
	3	−3	−7	−12	..	..	..	..	..	..
	6	−12	−19	−17	..	..	..	..	..	..
O	1	−23	−45	−46	−23	−45	−37	−92	..	..
	3	−33	−41	−48	−26	−40	−29	−87	..	..
	6	−33	−37	−48	−29	−38	−28	−90	..	..
Z	1	−22	−23	−39	−12	−28	−30	−77	−9	−15
	3	−23	−34	−39	−23	−33	−32	−80	−9	−11
	6	−36	−44	−42	−40	−45	−48	−82	−10	−15
BB	1	−2	−7	−1	..	..	..	−11	..	..
	3	−6	−13	−7	..	..	..	−36	..	..
	6	−9	−16	−9	..	..	..	−45	..	..

Aluminum and Aluminum Alloys.—The decrease in percentage elongation for the aluminum alloys is quite marked. This is particularly true with alloys O (duralumin) and Z (1 per cent silicon, 0.5 per cent magnesium). However, the loss apparently is not progressive since the loss after one year is virtually as great as after 6 yr. (see Table VI). Alloy FF (aluminum-coated duralumin) has lost little of its original ductility and exhibits quite satisfactory behavior on the whole. Further work along the lines of that described by Dix[19] is needed in order to evaluate the effect of thickness on the change in ductility. The work reported by Dix does indicate that the loss in elongation is materially reduced with thicker sections. However, there is a definite need for a thorough study of the subject—not only on aluminum and its alloys, but also on the other metals and alloys.

Nickel and Nickel-Copper Alloy.—The alloys S (nickel-copper) and T (nickel) show no significant change in elongation at any location.

Lead, Lead-Antimony, and Tin.—Alloy U (lead) shows no significant loss in elongation, although the losses are quite high at Rochester and La Jolla. Alloy CC (lead-antimony) has appreciable losses at Altoona, Rochester, and La Jolla. Alloy EE (tin) behaves poorly in the marine atmospheres.

Zinc.—The three zincs show appreciable losses in the industrial atmospheres and at La Jolla. The change is progressive (see Table VI) with time. The elongation of the purer alloys (BB and HH) is less affected by corrosion than that of alloy AA.

Visual Appearance of Alloys:

The descriptions of the visual appearance of the alloys made by the members of the inspection subcommittee are concise, clear, and to the point.[20] These descriptions will prove to be valuable aids in selecting structural materials from the appearance standpoint. The notes on the character of attack are also of considerable value in interpreting the results of the physical property tests. Their value in this respect will grow in importance as the test continues. However, no other conclusions regarding the utility of the various alloys can be drawn from such results.

General Discussion of Test Program and Conclusions:

Considering only the results of the tension and elongation tests as a basis for discussion, the several limitations of the data should be clearly understood. The data are not basically suited to very narrow comparisons due to the fact that the change of properties can only be measured by noting the changes of the mean values of two separate sets of specimens. Thus, a single value must represent the change for any material, and the usefulness of tests of significance is distinctly limited. Furthermore, the results must be considered as only rigidly valid for thin-gage sheet mounted vertically, until such time that we have further information on the influence of size, shape, and position for each material. It is quite certain that all these factors are influential in determining the time change of physical properties. The use of machined tension specimens has been questioned and the suggestion is made that the 9 by 12-in. specimens be machined to tension specimens at the end of the test and used to check the tension and elongation results. It is felt, also, that the present test would have been strengthened had each material been chosen from several commercial lots and the allocation of specimens made by chance, but restricted so that each lot of material would be represented in each test sample. Such a test sample would have been more representative of the material. The effect of possible variations in material from point to point would have been controlled and the anomalous results met with in the present data probably avoided.

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[20] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, pp. 202-213 (1938).

The outstanding feature of the results is the inherent resistance to corrosion by non-ferrous metals in general. Considering the thinness of the sheet used, it is remarkable that only a few materials have shown really appreciable losses in strength and ductility. Many of those materials, furthermore, apparently undergo but slight changes after the first period of exposure.

Remembering the foregoing limitations, one can make a rough rating of the corrosion resistance of the alloys under test. Three classes of resistance have been chosen, *A*, *B*, and *C*, in descending order of resistance. The order of listing of alloys in each class is alphabetical (Table VII).

TABLE VII.—CLASSIFICATION OF ALLOYS IN ORDER OF THEIR RESISTANCE TO CORROSION AS JUDGED BY LOSS IN TENSILE STRENGTH AND ELONGATION.

Industrial				Seacoast			Rural	
Pittsburgh, Pa. 1	Altoona, Pa. 2	New York City 4	Rochester, N. Y. 6	Sandy Hook, N. J. 5	Key West, Fla. 7	La Jolla, Calif. 9	State College, Pa. 3	Phoenix, Ariz. 8
CLASS *A* Tensile loss, 5 per cent or less Elongation loss, 10 per cent or less								
A, B, D, S U, CC, FF	A, B, D, N, P, Q S, U, FF	A, B, C D, Q, S U, CC FF	A, B, C, D F, I, L, M N, P, Q, S T	A, B, C D, I, L N, P, Q S, T, U, CC, FF HH	A, B C, D F, I, L M, N P, S T, U AA, BB CC, FF HH	B, D, F L, M, N P, Q, S T, U, FF	A, B, C, D F, G, I, K L, M, N, O P, Q, S, T U, Z, BB CC, FF HH	A, B, C, D F, G, I, L M, N, O, P Q, S, T, U AA, BB, CC FF, HH
CLASS *B* Tensile loss, 10 per cent or less Elongation loss, 20 per cent or less								
C, F, G, I L, N, P, Q T	C, F, G I, L, T CC	F, I, L N, P, T	G, U, BB CC, EE FF, HH	F, G, M AA, BB	G, Q	A, C, CC	AA, EE	K, Z
CLASS *C* All others.								
K, M, O, Z AA, BB, EE, HH	K, M, O Z, AA BB, EE HH	G, K, M O, Z, AA BB, EE, HH	K, O, Z AA	K, O, Z EE	K, O Z, EE	G, I, K O, Z, AA BB, EE HH		EE

No allowance has been made in these ratings for significance of results. It is felt that large changes in strength or elongation are important in any event. If they are not significant, the material shows high variability—a distinct disadvantage in itself. The boundaries of the groups are strictly arbitrary, but the resulting grouping is quite reasonable. The relative ratings of the alloys may well have to be modified after the next test period, particularly in view of the likely differences in the time-corrosion curves of the various materials. However, in view of the general agreement with a similar rating made by Finkeldey[21] at the end of only one year's exposure, it is felt that the rating should serve as a good guide in the choice of thin sheet materials for use without protective coatings.

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[21] W. H. Finkeldey, "The Early Interpretation of Test Results in the Atmospheric Corrosion of Non-Ferrous Metals and Alloys," Symposium on Outdoor Weathering of Metals and Metallic Coatings, pp. 76-78, Washington Regional Meeting, Am. Soc. Testing Mats. (1934). (Available as separate publication.)

In conclusion, special recognition should be given to the personnel of Committee B-3, and especially to those members of Subcommittee VI who have devoted so great an amount of time and energy to the successful, although at present only partial, fulfillment of an extremely ambitious and valuable test program. The results of this work will help greatly towards a better understanding of the nature and extent of atmospheric corrosion. Already, the results have opened many new problems to be solved, but our knowledge of the atmospheric corrosion of non-ferrous metals has made a great advance.

DISCUSSION

Mr. H. F. Dodge.[1]—I think Mr. Borgmann is to be warmly congratulated on the thorough analysis he has made of these results. His suggestion that the standard deviations as well as the averages of samples be presented is an excellent one. If this is done, the essential information contained in the data will be made available for such further analysis as the committee may wish to carry out. I should like to raise one question, however, with respect to the statement he makes relative to formulas for standard deviation. On page 677 he gives a formula for estimated standard deviation. At the top of page 678 he states: "The above formula gives a somewhat more conservative estimate of the standard deviation of small samples than the one suggested in the A.S.T.M. Manual." The statement that this formula gives a "more conservative estimate" is misleading, I feel, inasmuch as the manual formula relates specifically to the observed standard deviation in the sample and not to an estimate for picturing what a very large number of tests would show. The proposal to publish an estimated value of standard deviation as against the observed standard deviation raises certain questions that should receive careful consideration. Presenting an estimated value for individual samples of six specimens each might be useful if the sole purpose of the tests were to consider each sample separately rather than to consider that sample as one providing partial evidence in the whole series of tests. Actually, I believe that the committee is interested in correlating or bringing together the cumulative results at the end of 1, 3, 12 yr., etc., to get a picture of the general tendency of the over-all results, rather than to consider separately the results of individual samples at each test period. I believe that the most useful form of presentation, when this is the case, is to present the observed standard deviation in a sample rather than an estimated value, that is, to present what you might call factual data rather than an interpretation.

Mr. R. F. Passano.[2]—The comments which Mr. Borgmann makes about change of strength are based in the case of each material on a comparison of the tensile strengths shown by two samples of six specimens. One of these was in storage for 6 yr., while the other was out-of-doors for approximately the same length of time. He chooses to compare the two samples by one statistical technique where Subcommittee VI of Committee B-3 chose to use another.

It happens that exposed and storage samples have been broken on three different occasions: after 1, 3, and 6 yr., approximately. Also, one sample of each material was broken originally in order that something might be known about initial properties. I hold that the information in all of these samples should be taken into consideration by anyone who attempts a judgment of the materials and the way in which they corrode.

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[1] Member of Technical Staff, Bell Telephone Laboratories, Inc., New York City.

[2] Research Engineer, The American Rolling Mill Co., Middletown, Ohio.

As an illustration, the accompanying Table I gives data on material AA, Prime Western zinc, for the storage samples, and those exposed at Altoona and State College, Pa.

So far as the storage samples allow one to go, the material is uniform. This is worth knowing, as we shall see later. Under these conditions, the average tensile strength of 29,604 psi. is a better value for the strength before attack than the strength of the individual samples of which it is an average. Using this value as the initial strength, the material has lost 937, 2404, and 4771 psi., respectively, for the three inspection times at Altoona. These are differences between a sample of 24 and a sample of 6. The standard deviation of these differences is about 115 psi. They reduce to annual losses in tensile strength of 780, 766, and 786 psi., for the three periods, or approximately 2.6 per cent of original strength[3] per year.

At State College, the material lost 604, 1004, and 1837 psi., respectively, for the three periods. These reduce to annual losses of 525, 313, and 302 psi., or approximately 1.3 per cent of original strength per year.

From what we know about the protection given by zinc coatings of different weights, one would expect zinc to corrode in direct proportion to time. These losses of strength are in accord with that observation,[4] although the relative activity of the State College atmosphere with respect to that of Altoona as shown by the tensile strength samples is very different from the relative activity of the two as shown by the galvanized sheet samples exposed at a different angle.

TABLE I.—PRIME WESTERN ZINC.
Tension Samples, 0.035 in. Thick

Identification	Storage Samples, $n = 6$		Samples Exposed at Altoona, Pa., $n = 6$			Samples Exposed at State College, Pa., $n = 6$		
	$\bar{X}$	σ	Exposure Time, yr.	$\bar{X}$	σ	Exposure Time, yr.	X	σ
Initial	29 900	283	......	......	......	......	......	......
1 yr.	29 600	200	1.20	28 667	345	1.15	29 000	216
3 yr.	29 533	309	3.14	27 200	183	3.21	28 600	271
6 yr.	29 383	90	6.07	24 833	121	6.07	27 767	75
	$\bar{\bar{X}} = 29\,604$	$\bar{\sigma} = 221$						
	$\pm 3\sigma_{\bar{X}} = 312$	$\pm 3\sigma_{\sigma} = 219$						
	Limits $\begin{cases} 29\,916 \\ 29\,292 \end{cases}$	Limits $\begin{cases} 440 \\ 2 \end{cases}$						

I was interested to know how the other two zinc materials, BB and HH, compared with AA. Let us look at the initial and storage samples of these materials.

	BB ($n = 6$)		HH ($n = 6$)	
	$\bar{X}$	σ	X	σ
Initial	18 300	146	18 800	438
1 yr.	18 583	69	18 567	160
3 yr.	18 333	125	18 433	134
6 yr.	18 800[a]	153	19 117[a]	206
	$\bar{\bar{X}} = 18\,503$	$\bar{\sigma} = 123$	$\bar{\bar{X}} = 18\,729$	$\bar{\sigma} = 235$
	$\pm 3\sigma_{\bar{X}} = 173$		$\pm 3\sigma_{\bar{X}} = 331$	
	Limits $\begin{cases} 18\,677 \\ 18\,331 \end{cases}$		Limits $\begin{cases} 19\,060 \\ 18\,398 \end{cases}$	

[a] Value high, outside limits.

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[3] The determination is a strength determination on the original cross-section measured before exposure. Loss of cross-section would be a more accurate description than loss of strength.

[4] This statement might be discussed at length considering State College data on AA, etc.

There is more variation in the strength of the unexposed samples of these materials than can be attributed to chance. What original strength can be assigned to either? No single value, certainly. It was variable perhaps from sample to sample for some simple reason such as variation in strength from edge to center of sheet. The samples of BB at Altoona which showed the following strengths after exposure are samples of unknown and indeterminate strength before exposure so far as we now know:

Exposure Time, yr.	$\overline{X}$ ($n = 6$)	σ
1.20	18 150	77
3.14	18 583	90
6.07	15 900	153

Perhaps someone equipped with detailed knowledge of the properties of sheet zinc and information of the way in which these particular sheets were sampled can clarify the performance of these two materials. Hardness measurements on individual specimens before pulling might be helpful. It cannot be done by statistical methods alone.

The point of view of this discussion differs from the one taken by Mr. Borgmann in his text. My recommendations might be summarized as follows:

1. Consider the information in the *several* unexposed samples of the material which have been broken.

2. (*a*) Under certain conditions, use the *average of the several* unexposed samples as the base from which to reckon the damage done to the samples which have been exposed.

(*b*) Under certain other conditions, be cautious about the *apparent damage* done by the exposure unless one knows the cause of the variation from sample to sample.

3. Examine the differences between original properties and those determined after exposure at each location for the effect of time, taking into account the chance variable of sampling.

4. Where the effect of time is linear, summarize as annual loss of cross-section or thickness, percentage loss of strength, or the like.

If I read Mr. Borgmann's text correctly, it is his recommendation that this experiment would have produced more information had each sample of six specimens been composed of one specimen from each of six commercial lots instead of six specimens from one lot of material. His hope, I think, is that such a sampling might enable one to estimate the effect of, say, lead and cadmium on the corrosion of zinc. I do not agree with these recommendations. If I wanted to measure the corrosion of Prime Western zinc, I should sample several lots of this material from various sources, if possible, but each sample would be from one lot and source. This plan takes space, time, and patience. It is the way in which research workers in this country have done things.

Mr. Borgmann's samples might be described as attempts at samples of American Prime Western zinc sheet. Such samples do not interest me. This grade of material purchased and delivered for use in construction is specifically one or more lots from one or more sources. The material is used from the first of lot A to the last of lot Z. The properties of the material in lot Z are not going to assist in the success of units built from the material in lot A. I advocate the type of sampling which Subcommittee VI of Committee B-3 did.

Mr. Borgmann's recommendation in the long run means "Take less data." In my experience, I have never had too many observations. I have often wished it were possible to get by with fewer measurements. The more measurements one makes, the more complications one uncovers. This holds even for established laboratory procedures. Under such conditions, one may estimate something from the data taken during the first exploration. When repetition shows that there are grounds for doubting the first numbers, what alternative is there to seeking a condition of constancy where one knows within limits what another experiment will produce? In my opinion, Mr. Borgmann is either very optimistic or so far in advance of his contemporaries that he should elaborate with examples.

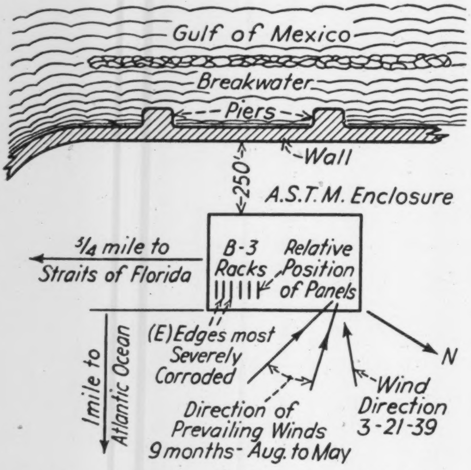
Gulf of Mexico
Breakwater
Piers
Wall
250'
A.S.T.M. Enclosure
3/4 mile to Straits of Florida
B-3 Racks
Relative Position of Panels
(E) Edges most Severely Corroded
N
Direction of Prevailing Winds 9 months- Aug. to May
Wind Direction 3-21-39
1 mile to Atlantic Ocean

FIG. 1.—A.S.T.M. Exposure Test Station at Key West, Fla.

MR. E. H. DIX, JR.[5]—I want to take this opportunity to emphasize one point of Mr. Borgmann's very excellent analysis. He has drawn attention to the fallacy of saying that these tests represent corrosion conditions of a locality such as, for example, Key West or La Jolla, without specifically stating the exact location of the test rack and the conditions surrounding the test rack. I will give you a very good example. At Key West the specimens are exposed in a large flat area where the sun beats down most of the time. They are within perhaps two hundred or three hundred feet of the salt water on the southwest side, and naturally it might be stated that our samples are within two hundred or three hundred feet of the ocean (see accompanying Fig. 1). As a matter of fact, on the northeast side the salt water is much farther away—a mile or more. The prevailing winds are from the east, across the Keys. For this reason, the edges of the specimens closest to the water on the southwest are much less attacked than the edges farthest from the water, that is, on the northeast. Now, if the prevailing winds had happened to be from the west rather than the east, the severity of the corrosion at this station would be definitely greater. Likewise, it is not correct to make a comparison between exposures at La Jolla and at Key West or Sandy Hook as being typical of the corrosion conditions on the west coast and on the east coast, respectively. It is well known that the test racks at La Jolla, because of their location at the bottom of a cliff and close to the ocean, receive a great deal of salt spray which generally does not occur at the other locations.

MR. WILLIAM BLUM.[6]—Just a very brief reference to the effect of differences in location. Electroplated steel with zinc or cadmium coatings at Key West and Sandy Hook yielded conclusive evidence that there is sulfur dioxide in the air at Sandy Hook, but not at Key West. The latter is a marine location with nothing else but salt water; the other has salt water plus sulfur dioxide.

MR. W. H. FINKELDEY.[7]—With reference to the difference between the two locations, Key West and La Jolla, Mr. Borgmann's description of the La Jolla location is correct—it is bathed frequently by the salt spray; but I also want to point out that La Jolla has 11 in. of rainfall while Key West has 45 in. All along that part of the West Coast fog conditions are frequent for quite a long period of the year, and these heavy fogs wet down the samples more often than the salt spray from severe storms. The little rainfall which does fall at La Jolla is useful in preventing corrosion because it gives the specimens a good washing, removing salt and other corrosion products which are accelerating corrosion.

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[5] Chief Metallurgist, Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pa.

[6] Chemist, National Bureau of Standards, Washington, D. C.

[7] Member of Firm, Singmaster & Breyer, New York City.

In view of the marked difference in weather conditions, I do not agree with Mr. Borgmann in his comment that points along the New England coast might approach the corrosiveness of La Jolla. The New England coast has approximately three times as much rainfall as La Jolla, a wider range of temperatures with much lower temperatures in the winter time, and marked differences in wind velocities. For example, the average of the maximum wind velocities along the West Coast is probably in the order of 30 m.p.h., whereas a similar average of maximum wind velocities along the New England coast would probably approximate 50 m.p.h.

I wish again to call attention to the fact that we spend a lot of time studying what happens to materials in the atmosphere but we have not spent enough time studying the atmosphere itself and determining which of its various components are the responsible factors in causing corrosion at our several test locations.

MR. C. W. BORGMANN[8] (*author's closure by letter*).—I welcome the discussion by Mr. Dodge with reference to the difference between "the estimated standard deviation" as used in my paper and "the observed standard deviation" suggested in the A.S.T.M. Manual. In the light of his explanation, I must withdraw my statement concerning the relative advantages of the two parameters in question. However, I must take issue with his suggestion that it is only through the use of the *observed* standard deviation that a picture of the general tendency of the test can be obtained. I believe that it can be shown that the estimated standard deviation is just as useful for such a purpose. To be more specific, I feel that the rational use of either function will lead one to the same conclusions concerning the significance of data in question. Such is shown to be the case in the present paper, and I certainly do not want to suggest that the present methods of analysis be changed.

I am pleased to have the additional information concerning the influence of physical location and climatic conditions on corrosion as given by Messrs. Dix, Blum, and Finkeldey. I am in hearty accord with the ideas expressed. However, I still hold to my original views concerning conditions along the rocky areas of the New England coast. I understand from Mr. R. B. Mears of the Aluminum Research Laboratories that experience at Point Judith, Conn., bears out my statement, at least qualitatively. Naturally there are many differences—wind velocity, fog, and temperature—between these locations. Hence, other than a qualitative agreement cannot be expected.

I was interested in Mr. Passano's analysis of the results on zinc AA from Altoona and State College. The idea of combining the results from all the storage samples is an excellent one and, of course, increases the precision of the determination. Unfortunately, however, very few of the metals behave as simply as does zinc AA. Real changes in physical properties can occur on simple aging of some alloys. Then, too, certain materials are far more irregular in their properties than others. Hence, if the storage specimens are chosen in any sort of fashion other than a pure random selection, it is quite impossible to distinguish real changes from those due solely to sampling. It seems to me that any use of statistical methods on the A.S.T.M. data must be carefully watched. The whole foundation for the validity of such methods rests upon the assumption that the test lot represents a random sample. As such samples were not taken, one must expect certain inexplicable results—such as occur throughout the present test data. However, the larger effects of corrosion will, of course, be possible of determination and hence, the engineering value of the test will not be materially reduced. The results will have to be viewed more from a common-sense standpoint, forgetting all except the possible implications of the minor effects.

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[8] Head of Department of Chemical Engineering, University of Colorado, Boulder, Colo.

The suggested use of an annual loss is perfectly satisfactory in its place. However, the number of cases where such a value can be rationally used is so limited that it seemed undesirable to do so in my analysis. In fact, I feel that Mr. Passano has stretched a point in combining the three values for State College—525, 313, and 302 psi.—into a single annual figure.

The table of results for materials BB and HH clearly brings out the difficulties previously suggested concerning the use of an average of all storage sets as a basis of judgment. Three of the eight averages fall outside the 3σ limits—indicating, it seems to me, the poor sampling technique used. Mr. Passano undoubtedly neglected to indicate that the initial value for material BB is also outside the 3σ limits.

The third recommendation of Mr. Passano that the effect of time on the properties of the materials be shown is a good one. I felt, however, that it was too early to make a real evaluation of this change on the majority of materials and that such an evaluation could better be made in the final report of the work.

I regret that Mr. Passano has seen fit to question my belief in "The American Way" and hasten to add that there is no need to send Mr. Dies to Colorado. Seriously, however, it has always been my feeling that a worker in the realm of science and engineering should be ready to accept helpful ideas from other fields of endeavor and other parts of the world. The ideas of test design that I have tried to indicate are widely used in the biological field. I have simply tried to apply them to engineering problems—such as corrosion—where the problem is such a general one that control of conditions imposes an unnecessary limitation on our results.

The reason for the use of certain types of factorial design is a simple one. If by a rational plan, one can determine the causes of certain effects under study with *equal precision* with a fewer number of tests, why not do so? I cannot enter into a complete discussion of factorial design and the analysis of variance in this discussion, but can simply restate my firm belief that these techniques can be happily adapted to the engineering field. The last statement by Mr. Passano is well taken. I have used the methods suggested in corrosion work, though unfortunately I changed positions before the completion of the tests, making it impossible to publish the results. I am now planning new experiments based on factorial design, the results of which I will submit for publication in an attempt to show more clearly the underlying ideas and the advantages of the method.

CHEMICAL REMOVAL OF CORROSION PRODUCTS IN THE DETERMINATION OF THE CORROSION RATE OF ZINC*

By E. A. Anderson[1] and C. E. Reinhard[1]

Of the methods of studying the corrosion of metals under various exposure conditions, that of measuring the rate of attack in terms of the changes in weight of test specimens has received the greatest amount of attention by corrosion workers. The most common plan of attack is to expose weighed specimens of known surface area which are removed at intervals, brushed lightly to remove loosely adherent dust and corrosion products, and are then reweighed and re-exposed.

It is recognized, of course, that the corrosion products remaining on the surface after brushing have definite weight but it is frequently assumed that when the curve showing the relation of weight loss to time of exposure takes a more or less straight line form, the weight of the corrosion products has reached a constant value and the slope of the curve represents the actual corrosion rate of the underlying metal. It is evident, however, that circumstances must exist under which a straight-line relationship may be obtained which does not represent a constant weight film of corrosion products. In such a case serious errors may result from attempts to estimate the corrosion rate and to predict the useful service life of a metal from the weight change data.

Removal of the corrosion products by chemical stripping suggests itself as the most reasonable method of obtaining a more nearly correct estimate of the corrodibility of a metal. The authors have recently completed a study of the corrosion rate of zinc in different periods of the day in which the method of chemical stripping was used in addition to the more common method of periodically weighing the specimens with the adherent corrosion products left in place. A study of the resulting data indicates that errors of considerable magnitude can result from acceptance of rates based on specimens weighed without removing the corrosion products.

Experimental Work:

The plan of the work was to expose outdoors at Palmerton, Pa.,[2] a series of rolled zinc specimens divided among four racks exposed as follows:

Rack	Exposure Period
No. 1	8:15 a.m. to 4:15 p.m.
No. 2	4:15 p.m. to 12:15 a.m.
No. 3	12:15 a.m. to 8:15 a.m.
No. 4	Continuous 24-hr. day

For the purpose, two grades of rolled zinc were selected. The one designated X-939 contained approximately 0.1 per cent of lead, 0.003 per cent of cadmium, and less than 0.01 per cent of iron; while the other, designated X-940, contained approximately 0.5 per cent of lead, 0.2 per cent of cadmium, and less than 0.01 per cent of iron. Both materials were available in the soft hot-rolled condition. Sufficient 4 by 6 by 0.024-in. specimens were cut from each grade of zinc to permit duplicate exposures on each rack. The surfaces were carefully cleaned with ether and alcohol and the pieces were weighed prior to exposure.

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* The presentation of this paper at the annual meeting was sponsored by Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys.

[1] Chief, and Investigator, respectively, Metal Section, Research Division, The New Jersey Zinc Co., Palmerton, Pa.

[2] The atmosphere at this location may be considered as mildly industrial. The rainfall, etc., are characteristic of the eastern part of Pennsylvania, but, due to its position between mountain ridges, fogs and heavy mists are probably more prevalent than normal.

The specimens were mounted 2¼ in. apart in the vertical position on porcelain insulators in galvanized iron racks (see Fig. 1). The racks were placed on a laboratory roof so that the specimen surfaces faced the direction of the prevailing winds. The three 8-hr. exposure racks were stored in a dry unheated room between exposures outdoors.

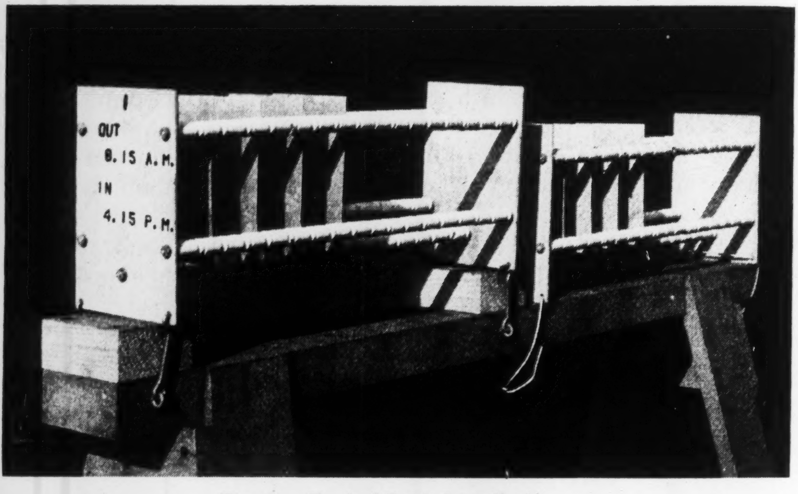

FIG. 1.—Typical Rack Installation.

At intervals during the exposure, which was started November 2, 1931, the specimens were removed from the racks, brushed lightly to remove loosely adherent dust and corrosion products, and reweighed. At the end of the 6-yr. period the adherent corrosion products were removed by immersing the specimens for 1 min. in a solution of 200 g. of chromic acid[3] per liter of water at 80 C. Blank uncorroded specimens similarly treated showed losses of 0.0007 g. and 0.0058 g. for X-939 and X-940, respectively. These corrections were applied to the data.

In all cases the agreement between the check specimens was quite good and in the discussion which follows only the average data are considered.

Experimental Data:

The average weight change data have been plotted for various times of exposure in Figs. 2 to 4, inclusive, and the final data after the 6-yr. period are assembled in Table I. On each curve has been indicated a point, marked *C*, representing the total loss in weight of the specimens, including the loss during chemical cleaning.

On each of the curves a dotted line

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[3] A word of warning should be given with regard to this stripping solution. The chromic acid should be substantially free of sulfates which convert it to an active etching solution. A grade suitable for use in chromium plating is satisfactory. In removing corrosion products developed in atmospheres containing sulfates or chlorides, contamination of the stripping solution and conversion of it to an active etching solution may occur. In such cases the solution should be replaced frequently and blanks should be run with the exposure specimens.

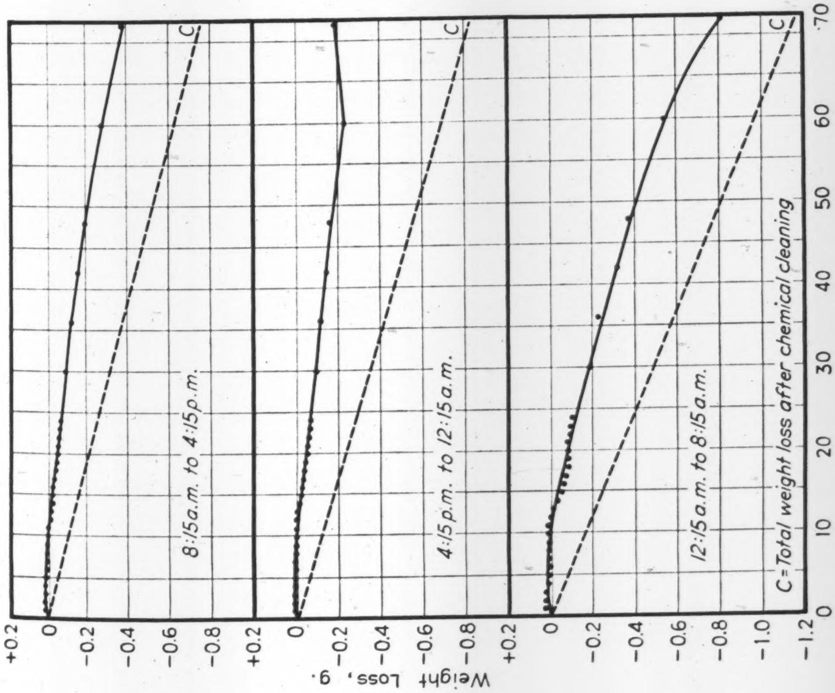

FIG. 2.—Weight Change Data for X-939.

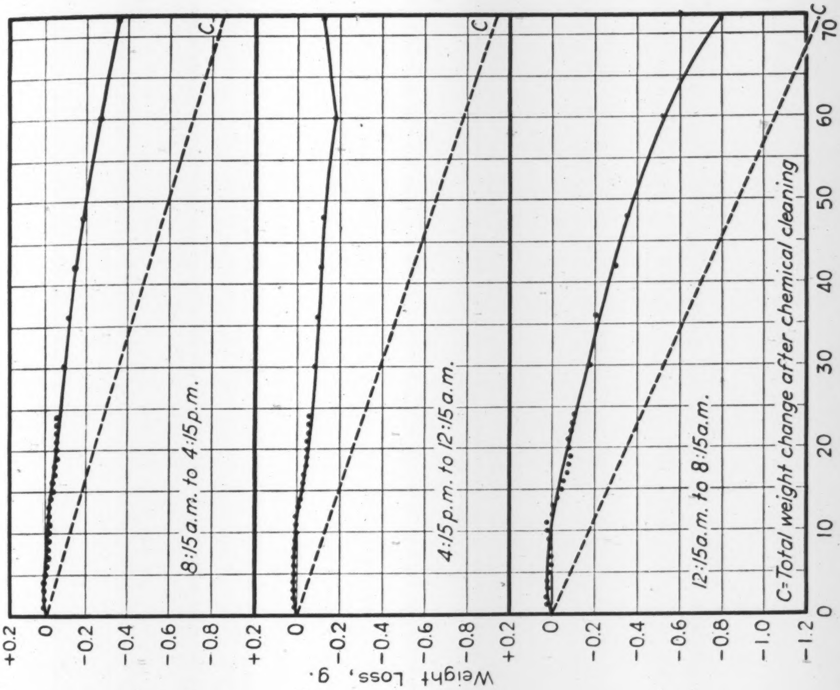

FIG. 3.—Weight Change Data for X-940.

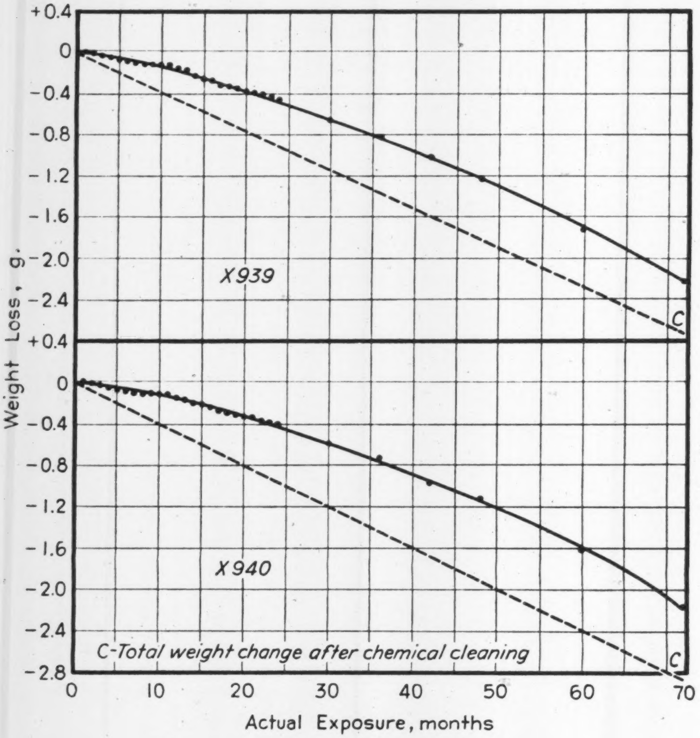

FIG. 4.—Continuous Exposure Tests.

TABLE I.—WEIGHT CHANGES IN X-939 AND X-940 EXPOSED 6 YR. IN PALMERTON ATMOSPHERE.

	Exposure Period	Weight, g.							
		Original	6-Yr., No Cleaning	Loss	After Cleaning	Loss in Cleaning	Blank Correction	Corrected Loss in Cleaning	Total Loss
X-939 - 1	8:15 AM to	69.7814	69.4018	0.3796	69.0208	0.3810	−0.0007	0.3803	0.7599
- 2	4:15 PM	70.7920	70.4076	0.3844	70.0349	0.3727	−0.0007	0.3720	0.7564
Average				0.3820				0.3762	0.7582
X-939 - 3	4:15 PM to	70.5684	70.3726	0.1958	69.7489	0.6237	−0.0007	0.6230	0.8188
- 4	12:15 AM	70.6118	70.4150	0.1968	69.7803	0.6347	−0.0007	0.6340	0.8308
Average				0.1963				0.6285	0.8248
X-939 - 5	12:15 AM to	70.4482	69.6351	0.8131	69.2885	0.3466	−0.0007	0.3459	1.1590
- 6	8:15 AM	69.3956	68.5688	0.8268	68.2156	0.3532	−0.0007	0.3525	1.1793
Average				0.8199				0.3492	1.1691
Total—Sum all periods				1.3982				1.3539	2.7521
X-939 - 7	24 hr.—	69.2775	67.0658	2.2117	66.5787	0.4871	−0.0007	0.4864	2.6981
- 8	continuous	69.4549	67.2078	2.2471	66.7075	0.5003	−0.0007	0.4996	2.7467
Average				2.2294				0.4930	2.7224
X-940 - 1	8:15 AM to	69.8862	69.5303	0.3559	69.0343	0.4960	−0.0058	0.4902	0.8461
- 2	4:15 PM	69.5658	69.2000	0.3658	68.7074	0.4926	−0.0058	0.4868	0.8526
Average				0.3608				0.4885	0.8493
X-940 - 3	4:15 PM to	69.7585	69.6396	0.1189	68.8368	0.8028	−0.0058	0.7970	0.9159
- 4	12:15 AM	71.4404	71.3122	0.1282	70.4738	0.8384	−0.0058	0.8326	0.9608
Average				0.1235				0.8143	0.9378
X-940 - 5	12:15 AM to	69.8372	69.0400	0.7972	68.5697	0.4703	−0.0058	0.4645	1.2617
- 6	8:15 AM	69.6878	68.8958	0.7920	68.4282	0.4676	−0.0058	0.4618	1.2538
Average				0.7946				0.4632	1.2578
Total—Sum all periods				1.2789				1.7560	3.0449
X-940 - 7	24 hr.—	70.3255	68.1148	2.2107	67.4167	0.6981	−0.0058	0.6923	2.9030
- 8	continuous	71.4678	69.3143	2.1535	68.6186	0.6957	−0.0058	0.6899	2.8434
Average				2.1821				0.6911	2.8732

has been drawn connecting the point *C*, representing the total loss in weight after 72 months exposure, with the origin. If the assumption is made that the corrosion rate was constant over the entire 6-yr. period, the slope of this dotted line would represent the true rate. It is impossible to state from these data whether this is so. An accurate determination could only be obtained by exposing a sufficient number of specimens to permit chemical cleaning and subsequent scrapping of specimens at appropriate intervals. As far as the authors are aware, this has not been done for zinc. However, experiments recently started have shown the rate to be constant within the limits of error in the measurements for determinations made six months and one year after exposure.

In the work of the Society's Committee A-5 on Corrosion of Iron and Steel it has been found that a straight-line relationship exists between the thickness of zinc coatings and the life of the coatings. These determinations involve no measurements of weight change but represent the exposure period required before rusting of the steel base has started. They are therefore free from the experimental difficulties under discussion here. The fact that the life of these zinc coatings does bear a straight-line relationship with the coating thickness indicates very strongly that the corrosion rate of zinc coatings is indeed fairly constant. It seems quite probable that an equal degree of constancy will ultimately be found for other zinc materials. The assumption will be made, therefore, in the remainder of this discussion that the corrosion rate is so nearly constant over the 6-yr. period that the slope of the dotted line may be taken to represent very closely the true rate.

Inspection of the curves in Figs. 2 to 4 reveals that no one of these curves has a slope equal to that of the dotted line, and hence no one of them indicates correctly the actual corrosion rate. The divergence of the weight change curves from the dotted line shows that the weight of adhering corrosion products is not constant but is increasing at a steady rate as the corrosion period is extended. How long this increase in weight of corrosion products will continue is not known from these data. The curves themselves show definite signs of curving downward, which might indicate that they would become parallel to the dotted line if the exposure were carried to a sufficiently long time. Under these conditions the weight of corrosion products would become constant and the slope of the weight change curve through the points of longest exposure would represent the true corrosion rate.

One of the functions of a corrosion engineer is to determine means of accurately estimating the corrosion rate of metals in the shortest possible time. Obviously he cannot afford to wait for the many years to elapse before simple weight change curves will become sufficiently accurate for his use, if indeed they ever reach this point. The method of chemical removal of corrosion products can be applied very early in the corrosion exposure.

Further examination of the curves shows that the weight of adhering corrosion products differs in the different exposures. It seems entirely probable that equally large and probably larger differences will be observed between different test locations in which differences in composition of the atmosphere, rainfall, fog, etc., are involved. It is entirely possible, therefore, that specimens exposed at two different test locations might show identical weight-change curves as determined on uncleaned specimens but would actually be corroding at different rates. Likewise, different zinc materials can, as shown below, develop corrosion films of different thicknesses and weight in the same exposure location which would lead to erroneous conclusions as to their comparative corrodibility.

One illustration of the changes which can take place in the weight of adhering corrosion products can be seen in the curves for the two zinc materials exposed in the period from 4:15 p.m. to 12:15 a.m. Both curves show a sharp upward break between the 60-month and 72-month exposures. There can be little doubt that this effect is real since it occurred on duplicate specimens of two different materials and only during this particular exposure period. Obviously, some change in atmospheric conditions during this period of the day had developed in this interval which permitted a bulkier corrosion film to remain on the specimens.

On the basis of the slopes of the weight change curves determined on uncleaned specimens, one would conclude that the corrosion rate of X-940 is slightly lower than that of X-939. Actually, the data obtained after chemical cleaning reveal that the reverse is true. While the difference between the two materials is very small in this instance, the possibility exists that errors of large magnitude might well result in other cases from conclusions based on weight changes on uncleaned specimens.

One other piece of evidence pointing to the validity of conclusions based on chemical cleaning of specimens exists in these data. It will be noted that the weight changes for the individual 8-hr. periods as measured after 72 months of exposure do not add up to the total for the continuous 24-hr. day exposure when the changes were determined on uncleaned specimens. On the other hand, a quite accurate correlation exists when the weight changes on chemically cleaned specimens are considered. Since the specimens placed outdoors for individual 8-hr. periods were under actual exposure for a total period of only 2 yr., the fact that the sum of the changes during the three periods adds up so closely to the total change after 6 yr. on the continuously exposed specimens indicates quite strongly that the corrosion rate had not changed between the second and the sixth year.

To return to the original intent of the experiment, it is clearly seen that a definite difference does exist in the rate of corrosion of zinc in different periods of the day. The corrosion occurring during the period from 12:15 a.m. to 8:15 a.m. is definitely greater than during any other period of the day and that occurring between 4:15 p.m. and 12:15 a.m. is slightly greater than that occurring during the daylight hours. There appears to be no question but that the corrosion rate of zinc, in this particular location at least, is greater during the night hours than during the daytime.

These differences might possibly be correlated with the rate at which the surfaces dry after rainfall during the various periods of the day, but the authors are inclined to feel that they really imply a definite effect due to the condensation of dews and mists on the surface. Such condensation products are most likely to contain relatively high concentrations of industrial gases such as SO_2 and would be expected to be definitely more corrosive to zinc than rain water.

Acknowledgment:

The authors wish to acknowledge the cooperation and assistance of other members of the Research Division of The New Jersey Zinc Co., particularly that of Mr. W. D. Hammel to whom credit for painstaking care in weighing the specimens and recording the data is due.

DISCUSSION

Mr. R. F. Passano.[1]—Subcommittee VIII of Committee A-5 on Corrosion of Iron and Steel now has exposed at Sandy Hook, N. J., samples of galvanized steel sheet and sheet zinc in the form of 4 by 6-in. specimens. It is our plan to determine loss of weight on these samples after exposures of 6 and 12 months at that place. The method of cleaning has not yet been fixed. I am sure there must be considerable background for the selection of chromic acid as a cleaning agent as described in this paper. The procedure for cleaning corroded zinc specimens in our laboratory begins with an overnight immersion in a solution containing 50 g. per liter of trisodium phosphate. This is supposed to make a fair conductor of the corrosion products. The corrosion products are then removed from the specimen with hydrogen, which is produced by a current of 75 amp. per sq. ft. flowing through a solution containing 50 g. per liter of disodium phosphate. The specimens are brushed lightly, rinsed, and dried before reweighing. Cleaning losses have been less than 0.005 g. on 4 by 6-in. specimens.

Mr. E. A. Anderson.[2]—We have tried a number of different methods, and there is at least one that is as acceptable as the chromic acid method, but we have adopted chromic acid for our own purposes.

Mr. W. H. Finkeldey.[3]—I should like to ask Mr. Anderson whether any attempt was made to analyze the corrosion product removed from those samples.

Mr. Anderson.—Not in this particular case. We have made a number of such studies on the type of corrosion products obtained in the atmosphere prevailing at Palmerton, which is mildly industrial. The corrosion products consist essentially of basic zinc carbonate. In more highly industrial atmospheres basic zinc sulfate predominates while in seacoast atmospheres we do find some basic zinc chloride.

Mr. Finkeldey.—It is surprising that the solid line curves do not show more corrosion.

Mr. Anderson.—The curves do show interesting variations in corrosion when they are inspected closely. You will notice that in the case of the continuously exposed rack seasonal variations occur that correspond to the dry periods in the summer.

Mr. Finkeldey.—Is there any particular local atmospheric contamination from the exhaust fumes of the laboratory?

Mr. Anderson.—That might come into the picture for a few days in the year. The prevailing winds are from the northwest and the rack was exposed on the windward side of the roof. Once in a while the winds would reverse and come from the east for two or three days, at which time some laboratory fumes might have been encountered. The laboratory itself is about two miles from the two plants and any atmospheric contamination would be somewhat general.

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[1] Research Engineer, The American Rolling Mill Co., Middletown, Ohio.

[2] Chief, Metal Section, Research Division, The New Jersey Zinc Co., Palmerton, Pa.

[3] Member of Firm, Singmaster & Breyer, New York City.

NICKEL-MOLYBDENUM-IRON AND RELATED ALLOYS—THEIR PHYSICAL AND CORROSION-RESISTANT PROPERTIES

By F. T. McCurdy[1]

Synopsis

Equipment for the newer chemical processes is constantly called upon to withstand higher temperatures and pressures and more corrosive reagents. Of the problems brought on by these factors, hydrochloric acid corrosion is especially difficult. Until quite recently, few metals could withstand this acid, and then only under mild conditions. Four strong, nickel-base alloys have now been developed, however, which are suitable. The first withstands hydrochloric acid of any concentration up to 70 C. (158 F.); the second withstands boiling hydrochloric acid; another wet chlorine at ordinary temperatures. Investigation has also led to a nickel-silicon alloy which is economical for sulfuric acid equipment.

The selection of materials for the processing, handling, storage and transportation of chemicals is constantly being made more complicated by newer processes and products. Many of the newer processes and improvements on the older processes involve increases in temperatures and pressures, and reagents of increased corrosive powers. The increase in the number of new chemicals developed has also added many products destructive to equipment that was otherwise perfectly satisfactory. The chemist is constantly inventing more economical but more strenuous processes, for which the materials engineer must furnish equipment strong enough and having a sufficiently long life to make the processes feasible.

Because acids have long been among the most difficult substances to handle, they have engendered considerable research on materials, especially metals. Sulfuric acid, for instance, could be handled, it was found, in lead, iron, or certain iron-silicon alloys, depending upon conditions (**1**).[2] The problem with nitric acid has been largely solved by the stainless irons and stainless steels which contain high percentages of chromium. Until 1929, however, no metals or alloys had been developed which could withstand hydrochloric acid economically under all conditions.

Hydrochloric Acid Equipment

At one plant, processing equipment for handling boiling dilute hydrochloric acid was at one time made of quarter-sawed cypress wood banded with iron straps which in turn were protected by lead sheathing. Hard-rubber-lined steel vats were also used for large equipment. Glass-lined steel and stoneware for kettles and tanks, rubber-lined iron or even wooden pipe, high-silicon-iron alloys, tile, mastic coatings, asphalt-base paints, and, in small but important parts, several noble metals—all these have served for hydrochloric acid equipment (2).

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[1] Superintendent, Haynes Stellite Co., Kokomo, Ind.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 709.

But for equipment for hydrochloric acid at high temperatures, wood, rubber compounds, and asphalt-base compounds are not very successful; glass, tile, and stoneware are brittle, and the noble metals are too expensive. Thus when the first hydrochloric acid-resistant alloy was produced in 1914 from nickel and molybdenum(3), it drew wide attention despite its high cost. Investigations in Germany during the 1920's showed that other less expensive nickel-molybdenum alloys were sufficiently resistant. Guertler, Rohn, Schulz, Jenge, and others (4) studied the problem, but even as late as 1929, only one such alloy had reached commercial production in Germany. This alloy contained approximately 15 per cent chromium, 7 per cent molybdenum and the remainder, nickel (1).

Two United States patents (5) were granted, relating to alloys of nickel, molybdenum and iron, in which the iron content was specifically limited to a maximum of 10 per cent. One of them also limited molybdenum to 10 per cent while the other specified a maximum of 40 per cent molybdenum.

Several other alloys have been used with success for dilute solutions of hydrochloric acid (6). Both monel metal and pure nickel depend for their resistance on the formation of a hydrogen film which polarizes the surface. If oxidizing conditions are present, or the acid concentration is increased, the hydrogen is depolarized and corrosion results. In still, dilute solutions, where there is no aeration, these metals can be used, monel metal being, in general, superior to nickel. Figure 1 shows typical curves for these two metals in various concentrations of still, unagitated hydrochloric acid at 25 C. (77 F.). The effect of agitation is clearly indicated when it is considered that in 10 per cent hydrochloric acid, not agitated, monel metal lost 0.2002 g. per sq. dm. per 100 hr., while in an aerated solution the loss was 1.632 g. (6). Because the bubbling caused some circulation, the specimen was later subjected to a similar test with bubbling nitrogen, in which case the loss was 0.5748 g. In quiet, oxygen-free solutions of 10 per cent hydrochloric acid, the corrosion rate for nickel is negligible.

A silicon-molybdenum-iron alloy containing 1 per cent of nickel is also used for handling hydrochloric acid. It is

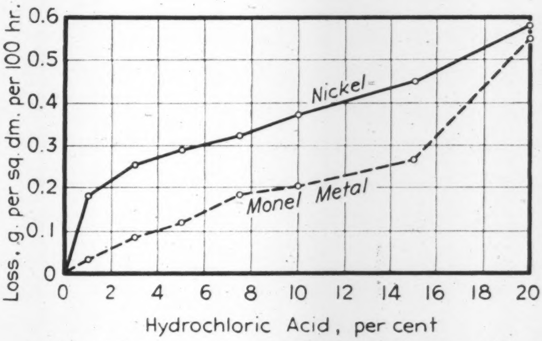

Fig. 1.—Corrosion Rates of Nickel and Monel Metal in Still Hydrochloric Acid Solutions (6).

hard and abrasion-resistant, but because it is unmachinable and unworkable, it can be used in the form of castings only. The surface of this alloy, upon exposure to hydrochloric acid gradually builds up a porous, gray film of insoluble salts which forms a highly protective coating. Thus while its corrosion rate at first is high, the rate gradually falls off until, after a number of hours, it becomes almost zero. The behavior of the alloy in concentrated hydrochloric acid at 25 C. (77 F.) is shown in Fig. 2. For the first 10 hr., the corrosion rate is fairly rapid, but it becomes negligible after 30 to 35 hr. The effect of more dilute solutions is to lengthen the time before zero corrosion rate is reached. At higher temperatures, the curve flattens out more rapidly.

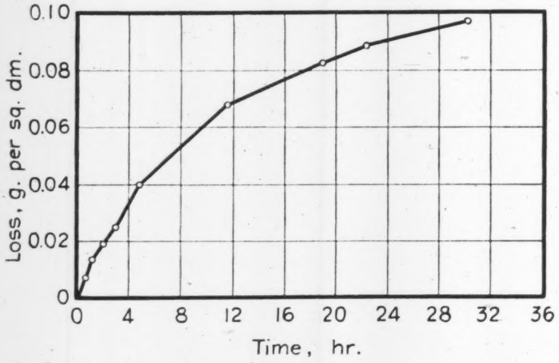

FIG. 2.—Corrosion-Time Behavior of Silicon-Molybdenum-Iron-Nickel Alloy in Concentrated Hydrochloric Acid (6).

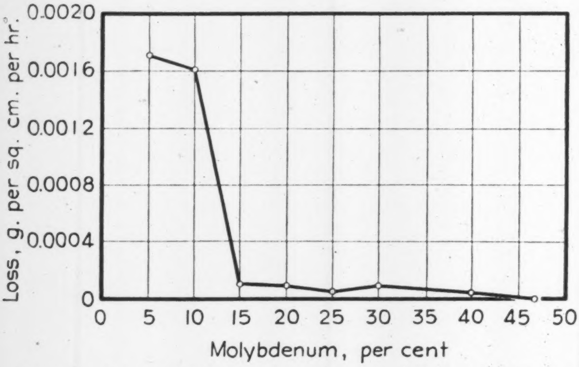

FIG. 3.—Corrosion Rates of Nickel-Molybdenum Alloys in 10 per cent Hydrochloric Acid at 70 C.

INVESTIGATION OF WORKABLE, RESISTANT ALLOYS

Investigations which led to the present alloys for hydrochloric acid service were carried out at Union Carbied and Carbon Research Laboratories, Inc., beginning about 1926. Prompted by the observation that certain complex nickel alloys showed a high resistance to acid corrosion, the investigation was confined at first to binary and, later, to ternary nickel alloys (1). A complete series of nickel-molybdenum alloys, containing

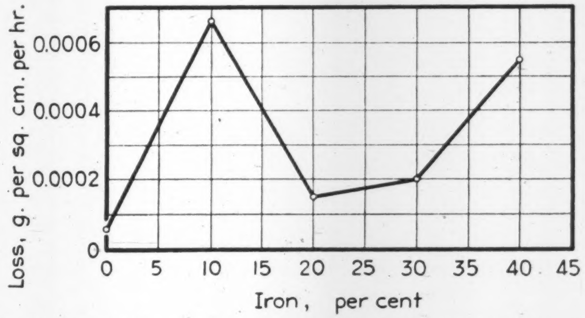

FIG. 4.—Corrosion Rates of Nickel-Molybdenum-Iron Alloys in 10 per cent Hydrochloric Acid at 70 C. (158 F.) (20 per cent Molybdenum, 0 to 40 per cent Iron).

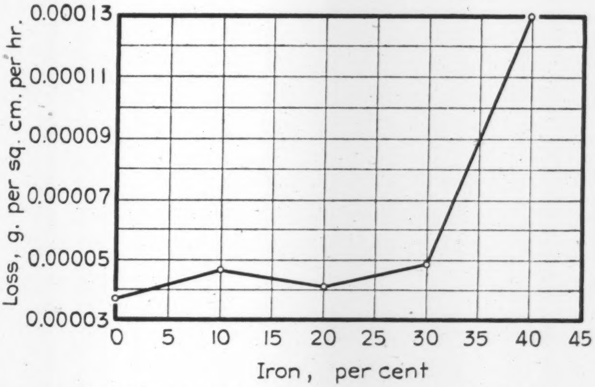

FIG. 5.—Corrosion Rates of Nickel-Molybdenum-Iron Alloys in 10 per cent Sulfuric Acid at 70 C. (158 F.) (20 per cent Molybdenum, 0 to 40 per cent Iron).

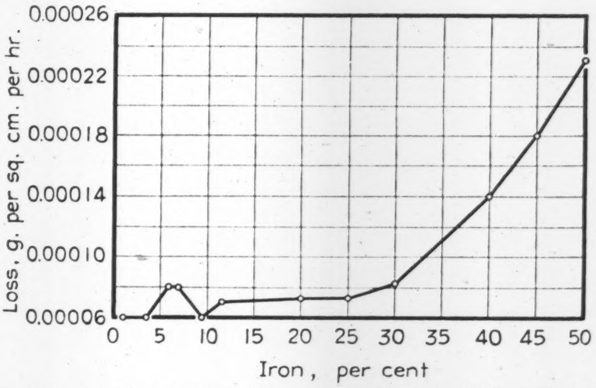

FIG. 6.—Corrosion Rates of Nickel-Molybdenum-Iron Alloys in 10 per cent Sulfuric Acid at 70 C. (158 F.).

molybdenum in amounts up to the eutectic at 49 per cent, was studied. Figure 3 shows the corrosion curve for binary nickel-molybdenum alloys with molybdenum varying from 5 to 47 per cent, in 10 per cent hydrochloric acid at 70 C. (158 F.). All the values given in this curve and subsequent charts are averages of at least 10 separate tests. While the alloys containing more than 15 per cent molybdenum are satisfactory from a corrosion standpoint, they have the disadvantage of being more expensive, and further investigation was made to determine to what extent iron might be substituted to reduce their cost and improve their workability.

Although it was believed at first that over 10 per cent of iron would adversely affect the acid resistance, investigation developed the interesting fact that maxima occurred in the corrosion rates between 5 and 10 per cent of iron. Beyond these maximum points, the curves

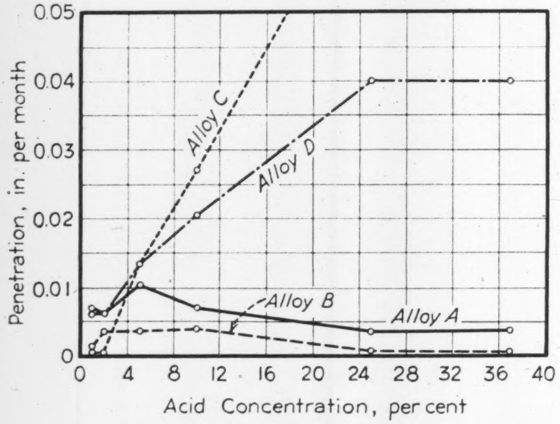

FIG. 7.—Corrosion Rates of Commercial Alloys A, B, C, and D in Aerated Hydrochloric Acid at 70 C. (158 F.).

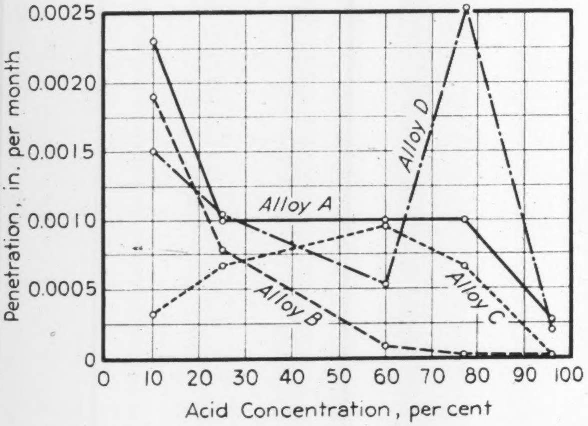

FIG. 8.—Corrosion Rates of Commercial Alloys A, B, C, and D in Aerated Sulfuric Acid at 70 C. (158 F.).

dipped again but with a second rise beyond 25 per cent of iron. Figure 4 shows the corrosion curve in 10 per cent hydrochloric acid and Fig. 5 shows the curve in 10 per cent sulfuric acid for alloys containing 20 per cent molybdenum and from 0 to 40 per cent iron. Similar curves were also obtained for alloys containing 15 and 25 per cent molybdenum with iron varying over the same range. All these curves bring out the fact that corrosion is not increased to a great extent until the iron proportion reaches at least 25 per cent. The effect of the iron content was studied later, after the effects of other elements in the composition had been studied. Figure 6 indicates that in 10 per cent sulfuric acid, the rate of corrosion of alloys containing between 15 and 25 per cent iron changes very slowly.

The selection of the final proportions of molybdenum and iron was an effort to compromise corrosion resistance, cost, and workability of the alloys. Figures 4, 5, and 6 show that an iron content as high as 20 per cent, with molybdenum also at 20 per cent, would be safe for acid service. With more than 20 per cent molybdenum, it would not be feasible to increase the iron appreciably, and the cost would therefore rise out of proportion to the corrosion resistance. With molybdenum present in excess of 20 per cent, the alloys become stiffer and more difficult to forge. Balancing the curves of the three most important factors, corrosion, cost, and workability, seemed to show that 20 per cent molybdenum and 20 per cent iron with the remainder chiefly nickel resulted in a satisfactory acid-resistant material.

TABLE I.—PHYSICAL PROPERTIES.

	Alloy A	Alloy B	Alloy C	Alloy D
Specific gravity:				
g. per cu. cm	8.80	9.24	8.94	7.80
lb. per cu in	0.318	0.334	0.323	0.282
lb. per cu. ft	549	577	558	487
Thermal conductivity, cal. per sq. cm. per cm. per sec. per deg. Cent	0.04	0.027	0.03	0.05
B.t.u. per sq ft. per in. per hr. per deg. Fahr	116	78.5	87	145
Mean coefficient of thermal expansion, per deg. Cent.				
0 to 100 C	0.0000110	0.0000100	0.0000113	0.0000110
0 to 1000 C	0.0000154	0.0000146	0.0000153	0.0000181
per deg. Fahr.				
32 to 212 F	0.0000061	0.0000056	0.0000063	0.0000061
32 to 1800 F	0.0000086	0.0000081	0.0000085	0.0000101
Electrical conductivity, mhos per cu. cm.	7.89	7.41	7.52	8.80

This alloy, which for convenience we have designated alloy A, has since been made available commercially in practically all forms—castings, forgings, rolled sheet and plate, and wire. The commercial alloy withstands the action of hydrochloric acid in all concentrations at temperatures up to 70 C. (158 F.), although the rate of attack increases slightly with the temperature (7). It is also resistant to sulfuric acid of any concentration up to 70 C. (158 F.) and to all concentrations below 50 per cent up to the boiling point. In addition, the alloy is resistant to acetic, formic, and other organic acids, but not to oxidizing agents. It stands up well in salt spray and is practically unaffected by alkalies. A curve showing its resistance to hydrochloric acid in various concentrations is shown in Fig. 7. Figure 8 shows its resistance to sulfuric acid. Determinations in hydrochloric and sulfuric acids are given for a temperature of 70 C. (158 F.) this being the highest temperature for which alloy A is recommended for service in these acids, except under

TABLE II.—MECHANICAL PROPERTIES.

	Alloy A		Alloy B		Alloy C	Alloy D
	Cast Metal	Rolled Metal Annealed	Cast Metal	Rolled Metal Annealed	Cast Metal	Cast Metal
Tensile strength, psi	69 000 to 77 500	110 000 to 120 000	75 000 to 82 000	130 000 to 140 000	72 000 to 80 000	36 000 to 40 500
Yield point, psi	42 500 to 45 000	47 000 to 52 000	55 000 to 57 000	60 000 to 65 000	45 000 to 48 000	....
Elongation in 2 in., per cent	8 to 12	40 to 48	6 to 9	40 to 45	10 to 15	0
Reduction of area, per cent	16 to 18	40 to 54	10 to 13	40 to 45	11 to 16	0
Rockwell, hardness	B 85 to 94	B 94 to 97	B 92 to 99	B 96 to 100	B 89 to 97	C 50 to 55
Brinell, hardness	155 to 200	200 to 215	190 to 230	210 to 235	175 to 215	....
Izod impact strength, ft-lb	25 to 35	62 to 77	11 to 16	68 to 78	....	....
Erichsen value, depth, mm	....	10 to 11	....	10 to 11	....	....
Short time tensile strength, psi.:						
at 500 C	....	90 000	....	115 000	....	....
700 C	....	55 000	....	85 000	....	....
900 C	....	40 000	....	50 000	....	....
1000 C	....	23 000	....	25 000	....	....
For less than 1 per cent creep per year at 900 C., max. load, psi	....	1 500	....	....	....	....
Transverse breaking load, 12-in. span:						
lb	....	....	....	....	....	5 000
deflection, in	....	....	....	....	....	0.070 to 0.080
Modulus of rupture, psi	....	....	....	....	....	78 000
Modulus of elasticity, psi	27 000 000		30 750 000		28 500 000	28 850 000

TABLE III.—RESULTS OF CORROSION TESTS.

(Rate of penetration is expressed in inches per month, and acid concentrations are expressed in percentage by weight.)

	Alloy A	Alloy B	Alloy C	Alloy D
Hydrochloric acid, 1 per cent, 70 C	0.007[a]	0.0019[a]	0.0002[a]	0.006[a]
1 per cent, boiling	0.0057	0.0007	0.008	0.0009
2 per cent, 70 C	0.006[a]	0.003[a]	0.0002[a]	0.006[a]
2 per cent, boiling	0.006	0.0009	0.02	0.009
5 per cent, 70 C	0.011[a]	0.003[a]	0.013[a]	0.013[a]
5 per cent, boiling	0.0224	0.001	0.04	0.05
10 per cent, 70 C	0.007[a]	0.0035[a]	0.027[a]	0.021[a]
10 per cent, boiling	0.023	0.001	0.22	0.11
25 per cent, 70 C	0.033[a]	0.0017[a]	0.08[a]	0.040[a]
25 per cent, boiling	0.030	0.002	0.60	0.12
37 per cent, 70 C	0.0037[a]	0.0016[a]	0.09[a]	0.04[a]
37 per cent, boiling	0.03	0.0016	0.28	0.12
Sulfuric acid, 10 per cent, boiling	0.003	0.0002	0.0042	0.0011
25 per cent, boiling	0.004	0.00015	0.0039	0.00074
60 per cent, boiling	0.033	0.0028	0.061	0.0026
96 per cent, boiling	0.64	0.038	0.026	0.035
Nitric acid, 10 per cent, room temperature	....	....	0.00096	....
10 per cent, boiling	....	....	0.0036	....
70 per cent, room temperature	....	....	0.00039[a]	....
70 per cent, boiling	....	....	0.165[a]	....
Phosphoric acid, pure				
10 per cent, room temperature	0.00018	0.00013	0.0000067	0.00012
10 per cent, boiling	0.0022	0.00015	0.00012	0.00023
50 per cent, boiling	0.0027	0.00014	0.00025	0.0041
85 per cent, boiling	0.068	0.00013	0.040	0.027
Phosphoric acid, technical				
10 per cent, boiling	0.00082	0.00030	0.00030	0.00044
50 per cent, boiling	0.0027	0.0018	0.0018	0.0020
85 per cent, boiling	0.0039	0.0028	0.0025	0.0031
Wet chlorine gas,				
Saturated vapor, room temperature	....	....	0.0032 max.	....

[a] Aerated test.

unusual conditions. Other corrosion test results are shown in Table III.

In physical properties, this alloy is very similar to high-strength alloy steel. It is readily machinable, makes good castings, and can be welded by either the oxy-acetylene or the electric arc process with full retention of its corrosion resistance. Because it is unusually strong at high temperatures, alloy A has been used in several applications based on this property alone; alloy A wire is being used in grids for radio receiving tubes. The physical and mechanical properties of alloy A are summarized in Tables I and II.

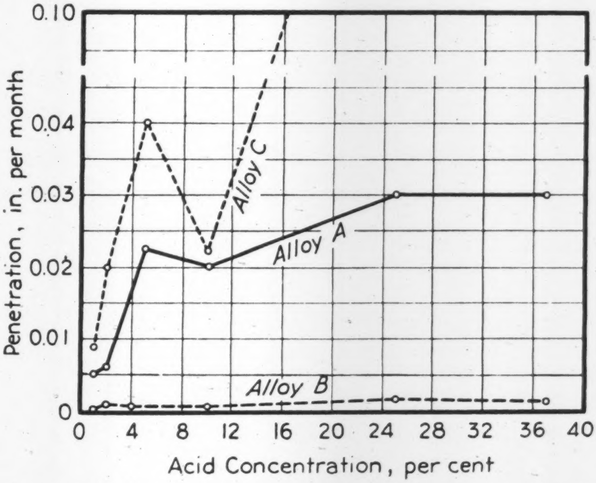

Fig. 9.—Corrosion Rates of Commercial Alloys A, B, and C in Boiling Hydrochloric Acid, Not Aerated.

This alloy contains a small proportion of carbides insoluble in solid solution even when cooled rapidly from a high temperature. Like austenitic-type alloys, it is appreciably hardened by cold work, with an increase in yield point and ultimate strength, and a corresponding reduction in ductility. The recommended annealing procedure is to heat it to a temperature of 1150 to 1180 C. (2100 to 2150 F.), hold at this temperature a short time according to the thickness of material, and follow by rapid cooling depending upon the size and shape of the part. This treatment softens the alloy and develops its highest corrosion resistance.

Molybdenum Content Increased

Alloy A, as mentioned above, is recommended for use only up to 70 C. For certain reactions, a material was needed that could withstand boiling hydrochloric acid. Increasing the molybdenum content of alloy A seemed likely to lead to good results, although the cost would be increased somewhat. With this in mind, further development was concentrated on an alloy containing approximately 30 per cent of molybdenum, 5 per cent of iron, and the remainder, nickel. At first, while the corrosion resistance of the alloy was satisfactory in boiling hydrochloric acid, only castings could be made. It was not until 1937 that developments had proceeded to a point where a commercially workable alloy of this analysis could be announced. This material, designated alloy B, is now available in practically every form—castings, forgings, hot-rolled bars, strips, plate, sheets, and wire. It is machinable and can be welded without loss of corrosion resistance.

Alloy B is outstanding for its high corrosion resistance in hydrochloric acid solutions of all concentrations and in all temperatures, including the boiling point as shown in Fig. 9. It has proved to be particularly economical for service in handling hydrochloric acid in the temperature range from 70 to 110 C. (158 to 230 F.), and in handling wet hydrochloric acid gas. Specimens of the commercial alloy now indicate that its penetration rate is only about 0.002 in. per year in a boiling 20 per cent hydrochloric acid solution. In acid concentrations below 10 per cent, it is notable that the aerated acid, at room temperature, is as corrosive on alloy B as is boiling non-aerated acid. As is seen in Table III, the aerated dilute acid at 70 C. (158 F.) is as much as three times as corrosive as boiling non-aerated acid.

Table II shows that the 30 per cent molybdenum alloy is considerably stronger than the 20 per cent molybdenum alloy, especially at elevated temperatures. For instance, it will be seen from this table that this alloy has a tensile strength of 115,000 psi. at 500 C. (930 F.) and 85,000 psi. at 700 C. (1290 F.). At ordinary temperatures, the elongation and reduction of area of rolled alloy B are fairly high considering that the metal has a tensile strength of between 130,000 and 140,000 psi. The heat treatment for softening alloy B and improving its corrosion resistance is the same as for alloy A.

CHROMIUM REQUIRED FOR OXIDATION RESISTANCE

These nickel-molybdenum-iron alloys while suitable for hydrochloric and sulfuric acids, are not sufficiently resistant to oxidizing conditions to warrant their use in nitric acid or in chlorine gas unless the gas is perfectly dry. The highly oxidation-resistant properties imparted to steel by chromium suggested that the addition of chromium to these alloys might improve their oxidation resistance, while they simultaneously retained their hydrochloric acid resistance. For this purpose, a series of chromium-bearing alloys were cast and tested for corrosion losses. Here again, a balance was struck between cost, chemical resistance, and workability. The alloy chosen for its best combination of properties was similar to alloy A, except that approximately 15 per cent of chromium was substituted for part of the iron content. A small amount of tungsten was incorporated to improve the properties still further. The resulting alloy is designated as alloy C.

The differences in the corrosion losses of alloys A and C in hydrochloric acid are shown in Table III. In sulfuric acid, alloy C is, in general, slightly better, except in concentrations below 10 per cent at temperatures approaching the boiling point. Alloy C, however, has remarkably good resistance to strong oxidizing agents such as nitric acid, free chlorine, aqueous solutions containing chlorine or hypochlorites, and acid solutions of ferric or cupric salts. It is quite resistant to phosphoric acid and highly resistant to acetic and formic acid.

Alloy C is now one of the few commercially available metallic materials possessing adequate resistance to hypochlorites and solutions containing free chlorine in appreciable concentrations, such as those used for bleaching purposes. However, this alloy may be attacked in solutions above room temperature, especially at temperatures over 40 C. (105 F.). At room temperature, the rate of penetration in wet chlorine gas is 0.038 in. per year, but at higher temperatures, local attack may occur.

Alloy C has a strength comparable with that of low- or medium-carbon cast steel, and, although its ductility is not as high as that of steel, it has considerable toughness for a cast material. The high percentage of elements usually considered as hardening constituents renders this alloy difficult to forge and roll, although it can be machined at slow cutting speeds. Small plates with a maximum weight of 100 lb. have been rolled of the alloy, however, and it is believed that the alloy will be useful in this form. Actually, the alloy is not exceptionally hard; it is believed, rather, that it is its structure which makes machining—and to an even greater degree, rolling—difficult. Recent studies have shown that its machinability can be improved by annealing for about 2 hr. at 1180 to 1205 C. (2150 to 2200 F.), and air cooling. This heat treatment results in an increase in both its ductility and corrosion resistance. In this condition, this alloy work-hardens rapidly, and for some machining operations a short hardening treatment at 870 C. (1600 F.) has been found preferable to the high-temperature softening anneal.

Welding does not affect the alloy's corrosion resistance, if done by an experienced operator who observes the necessary precautions. Heat treatment after welding is not usually necessary. The principal physical properties of this alloy are shown in Table I.

NICKEL-SILICON ALLOYS FOR SULFURIC ACID

The 14 per cent silicon-iron alloys have been used for some time for sulfuric acid service. A part of this investigation of nickel alloys was therefore directed to study nickel alloys containing silicon (1). It was found that nickel-silicon alloys, with up to 10 per cent of silicon, are fairly strong but not particularly acid-resistant; at about 15 per cent silicon they become resistant to acids but are very brittle (1). Approximately the same conditions are found with nickel-aluminum alloys, except that brittleness and resistance to acid do not occur until the aluminum content approaches 20 per cent. Of the ternary nickel alloys in this group, the only one that combines useful strength with fairly good acid resistance is one containing approximately 10 per cent of silicon and 5 per cent of aluminum.

In studying the effect of adding copper to the nickel-silicon-aluminum alloy, it was found that from 2.5 to 3 per cent of copper gave a finer grained and considerably stronger alloy. Metallographic examinations led to the idea that the sum of the silicon and aluminum should not exceed 12 per cent if the formation of certain inter-metallic compounds was to be avoided. The aluminum content was therefore lowered, the copper retained, and favorable results were secured at once. This alloy D, a nickel alloy which contains approximately 10 per cent silicon, 3 per cent copper, and a small amount of aluminum, makes strong, tough castings which are quite resistant to sulfuric acid.

While the resistance of alloy D to hydrochloric acid is not quite so high as that of the nickel-molybdenum-iron alloys, it is considerably above that of most commercial alloys. In 10 per cent hydrochloric acid at 70 C. (158 F.), it loses 0.0006 g. per sq. cm. per hr., corresponding to a penetration of 0.021 in. per month; but, unlike alloy A, it is somewhat less resistant to stronger hydrochloric acid concentrations. In sulfuric acid at 70 C. (158 F.), it shows practically the same resistance as alloy A, but at the boiling point it has better resistance, throughout the range of acid concentrations investigated, than alloys A, B, or C. In acetic and phosphoric acids, the alloy also compares favorably with alloys A and B.

Alloy D is not workable and is machined only with difficulty; it is best finished by grinding. In general, otherwise, its physical properties are similar to those of a high-grade cast iron (7). However, it has a higher transverse strength and good deflection, particularly after a toughening anneal. Its high silicon content imparts an average hardness of Rockwell C-50 to C-55, and low impact strength. Its hardness can be reduced to Rockwell C-45, and its toughness and impact strength appreciably increased, without effect on its corrosion resistance, by heating at 1000 C. (1850 F.) for 3 hr. and furnace cooling. Because of its hardness, alloy D possesses good abrasion resistance, and this property makes it particularly suitable for handling liquids containing suspended abrasive matter. Other physical properties of alloy D are shown in Table I.

Test Practices for Corrosion Determination

Because of the severity of corrosive media to which these nickel alloys are most usually subjected, severe limits have been established on the corrosion resistance of each. The only sure way found yet to assure that the alloys will be satisfactory in service is to pour corrosion test samples from every heat. Samples of alloys A, B, and D are poured as small pieces 1 by $1\frac{1}{2}$ by $\frac{3}{8}$ in. in size, and with a cored hole near one end. Alloy C samples are poured as a block approximately $\frac{1}{2}$ in. square and $1\frac{1}{4}$ in. long. All samples are ground to remove scale, are slightly polished, are rounded at their corners, and are carefully weighed.

The corrosion loss of alloy A is tested in a boiling 10 per cent hydrochloric acid solution; alloy B is run in boiling 20 per cent hydrochloric acid, alloy C is suspended in an atmosphere of wet chlorine at room temperature; and alloy D is subjected to boiling 77 per cent sulfuric acid. Short-time corrosion tests, usually between 15 and 20 hr., are run, and while these result in higher rates of weight lost than would be obtained from longer tests, experience over a long period has shown that these tests are sufficient to indicate whether or not the sample is satisfactory. Calculated in inches penetration per month, the average corrosion losses under the respective conditions are shown in Table IV.

TABLE IV.—SHORT TIME PENETRATION TESTS TO DETERMINE SUITABILITY

Alloy	Conditions	Allowable Penetration, in. per mo.
A.........	10 per cent HCl, boiling	0.020 max.
B.........	20 per cent HCl, boiling.......	0.003 max.
C.........	Wet chlorine, room temperature	0.0032 max.
D.........	77 per cent H_2SO_4, boiling	0.0156 max.

Because it is commercially possible to hold these four alloys within the prescribed limits of corrosion losses, they have been useful in many types of processing equipment. The ease of fabrication of alloys A and B, the good physical characteristics of all four alloys, and the excellent resistance of the alloys to such a variety of corrosive media has assured that they will be increasingly adopted for equipment handling strong chemicals.

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(6) F. A. Rohrman, "Resisting HCl Corrosion with Metals," *Chemical and Metallurgical Engineering*, Vol. 40, No. 12, December, 1933, p. 646.

(7) Haynes Stellite Co., "Hastelloy High-Strength Alloys for Corrosion Resistance" (1937).

DISCUSSION

Mr. John Howe Hall.[1]—I am impressed by the fact that the analysis of several of the alloys is not given with any degree of clarity. On page 706, second column, in describing alloy C, I notice that "*approximately* 15 per cent of chromium" and "*a small amount* of tungsten" make up the composition of this alloy, and similarly, on page 707, second column, second paragraph, alloy D contains "*approximately* 10 per cent silicon, 3 per cent copper, and *a small amount* of aluminum" and the balance nickel. I should like to see the composition more clearly stated.

Mr. G. F. Comstock.[2]—I should like to ask what, in general terms, was done to the composition known as alloy B to render it workable.

Mr. F. T. McCurdy[3] (*author's closure by letter*).—Answering Mr. Hall's question on the analysis: Hastelloy alloy C has a maximum content of 18 per cent chromium, 6 per cent tungsten, 7 per cent iron, 20 per cent molybdenum, and the balance nickel. Hastelloy alloy D has a maximum content of 11 per cent silicon, 4 per cent copper, and balance nickel.

Answering Mr. Comstock's question: no change was made in the composition of Hastelloy alloy B to render it workable. Alloy B is 65 per cent nickel, 30 per cent molybdenum, and 5 per cent iron. We have been able to work this alloy by very close control of the temperature at which it is rolled, the amount of draft given per rolling, and the number of passes made before it was advisable to reheat. Although this alloy cannot be worked in the manner in which steels are ordinarily worked, however, we have been able to successfully roll it into sheets.

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[1] Consulting Engineer, Philadelphia, Pa.

[2] Metallurgist, The Titanium Alloy Manufacturing Co., Niagara Falls, N.Y.

[3] Superintendent, Haynes Stellite Co., Kokomo, Ind.

FATIGUE MACHINES FOR TESTING STRUCTURAL UNITS

By R. L. Templin[1]

Synopsis

Fatigue tests of structural units such as joints, beams, columns, and frames, carried out under normal working loads, will give results which should be of considerable assistance in improving the design of such structural units so as better to withstand repeated service loads. This paper describes in some detail three types of relatively large fatigue testing machines which have been designed for the purpose just mentioned. The functioning and calibration of the machines is discussed in some detail and the results obtained from four years use are briefly indicated. A limited amount of test data is included.

Numerous instances have been observed wherein structures, or parts of structures, have failed under repeated loads. These repeated loads, in some cases, are appreciably less than the structures or members can carry safely under single application or static load conditions. The failures occurring under these conditions of repeated loads are designated as fatigue failures and almost invariably are associated in some way with joints or connections in the structures.

The investigation of the fatigue strength of structures subject to repeated loadings has received but little attention in this country until recently, although such investigational work has been under way for some time in other countries, especially in Germany.

In designing structures, such as bridges, for example, the customary procedure is to make assumptions relative to stress distribution in members, or transfer of load by rivets or welds, which neglect or ignore the relatively high actual stresses occurring at rivet holes, edges or ends of welds, and around openings for lightening or other purposes. These high local stresses in most cases do not cause any trouble under static load conditions but under repeated loads may, and frequently do, cause fatigue cracks with eventual failure of the member or structure.

In order that structures can be properly designed to withstand repeated loads, it would seem necessary to know the fatigue strength of the structural material used, the actual stresses in the various parts of the structure under the service loads obtaining, and the number of repetitions of such loads during the expected life of the structure.

The evaluation of the fatigue strengths of structural metals, however, is by no means as simple as, for example, the determination of their static tensile properties. The value determined for the fatigue strength of a metal depends upon the range of stress, the mean stress, the conditions of combined stress, the number of repetitions of stress, surface conditions of the specimen, corrosive conditions obtaining, temperature, and, in some instances, speed of testing. To consider properly the effect of all these factors would require much testing equipment and time resulting in a large cost for the desired data. Assuming for the moment that such information were available, the measurement or calculation of the actual stresses occurring at points of stress concentration in a structure or its component parts, under service conditions, is very difficult if not quite impossible in many cases. It appears more satisfactory, therefore, to attempt at least a partial, and probably an adequate, solution of the problem presented by making repeated load tests of actual joints, beams, columns, frames, and other component parts of structures. Such tests made under controlled conditions and carried out at accelerated rates but in the range of normal working loads, or slightly beyond, would result in data which should greatly assist the designer of structures subjected to repeated loads.

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[1] Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pa.

Description of the Machines:

With this purpose in mind a riveted-joint fatigue testing machine was designed and built early in 1935 and put into operation in August of that year by the Aluminum Research Laboratories, New Kensington, Pa. This first machine, Fig. 1, consists of two similar units, but both operated by a single 25-hp. geared motor. Each unit consists of a horizontal bed firmly attached to a concrete foundation, to one end of which a vertical member is rigidly attached. To the upper end of the vertical member a long horizontal double beam is attached by means of crossed plate fulcra. The horizontal beam is about the same length as the bed, and its outer end is attached through a single plate fulcrum to an adjustable-throw eccentric crank. The eccentrics of the two units are nominally 90 deg. out of phase to minimize peak loads in the motor and to improve the running of the machine. The test specimens are placed in the unit in a vertical position between the crank end and the fulcrum end of the machine, one end of each specimen being fastened to the bed and the other to the horizontal beam. When the specimen is in place and the crank or eccentric (not being set at zero throw) is turned, the upper horizontal

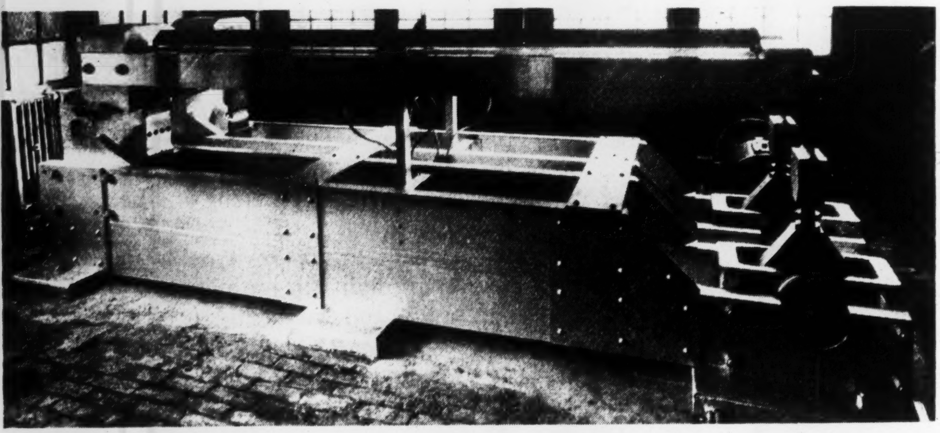

FIG. 1.—Repeated Joint Fatigue Testing Machine. Maximum loading range on specimen ± 40,000 lb.

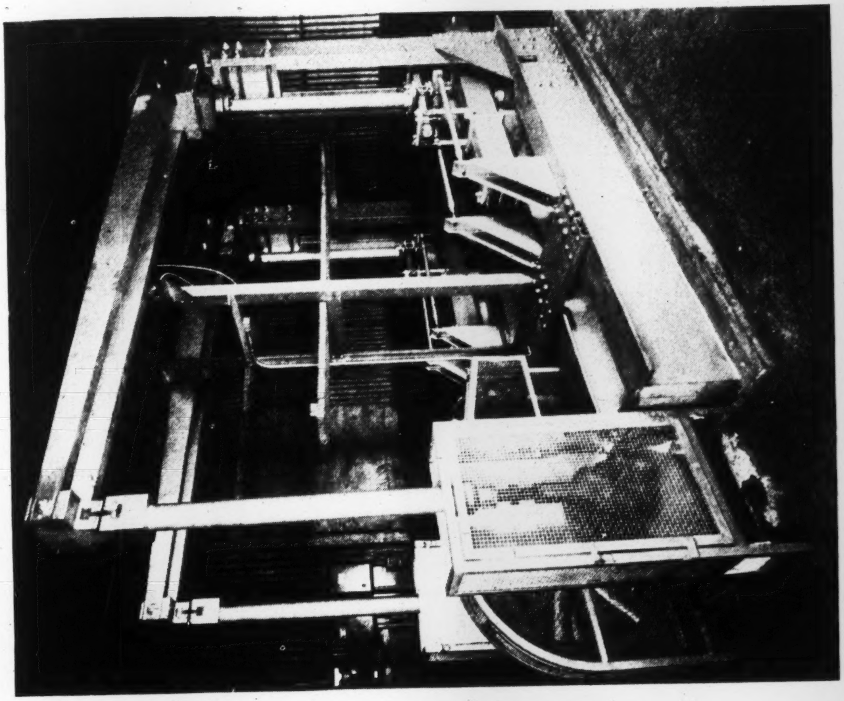

FIG. 3.—Fatigue Testing Machine Shown in Fig. 2 Arranged for Repeated Loading Tests on Beams.

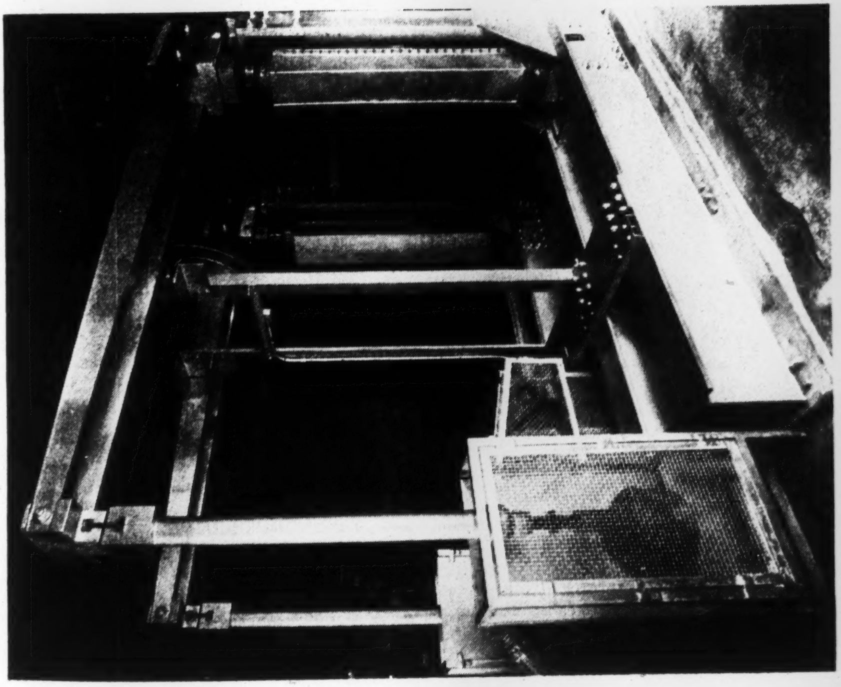

FIG. 2.—Fatigue Testing Machine for Columns, Beams and Frames. Maximum loading range on specimen ± 50,000 lb.

beam is moved up and down, applying either tension or compression to the specimen. As load is applied to the specimen, the upper beam deflects and the load applied is proportional to the change in deflection of the beam. The upper or movable beams then act as second-class levers of approximately 10 to 1 ratio, when the machine is operating.

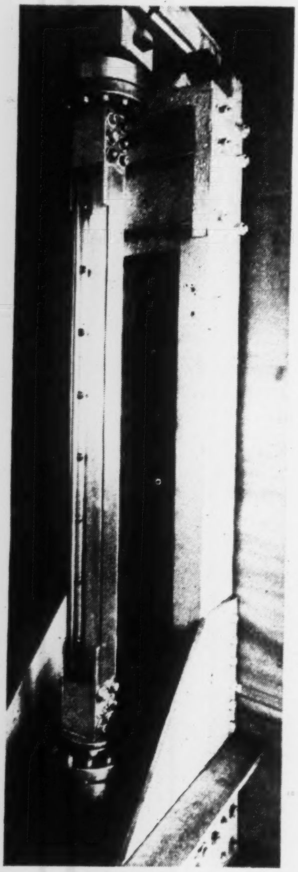

FIG. 4.—Close-Up View of Two Aluminum Angle Struts Being Subjected to Axial Repeated Load Test.

The maximum load that could be imposed on each specimen was originally 25,000 lb. either tension or compression, and the speed was 175 cycles per minute. A few months after the machine was put into operation it was decided to increase both its capacity and its speed by using larger loading beams and providing a new set of gears in the driving unit. These changes gave a maximum capacity in tension or compression of 40,000 lb., and a speed of 312 cycles per minute. The two units comprising this machine were designated Nos. 1 and 2.

In the fall of 1935 a column fatigue testing machine was designed and built. This machine (Fig. 2), which was installed in June 1936, had a different type of drive and an improved design of eccentric for changing the load range In addition provision was made for applying load through plate fulcra at each end of the specimens.[2] The maximum capacity in tension or compression of this machine is 50,000 lb. and the maximum length of specimen which can be tested is much greater than in the riveted-joint machine. In addition a greater throw of the eccentrics has been provided. This machine is operated at 210 cycles per minute, using a 15-hp. motor. The units of this machine have been designated as Nos. 3 and 4.

During the latter part of 1937 this column fatigue testing machine was modified so that it could be used for testing beams, as well as columns or frames, under repeated loads. Some of these modifications are shown in Fig. 3. When used for testing beams or frames, certain limitations of size and deflection must be observed as indicated in Table I. Figures 4 and 5 are close-up views showing struts and beams in this machine.

In September, 1937 two additional riveted-joint fatigue testing machines (Fig. 6), combining the loading princi-

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[2] Fred S. Eastman, "Flexure Pivots to Replace Knife Edges and Ball Bearings," *Bulletin No. 86*, University of Washington Engineering Experiment Station, November, 1935.

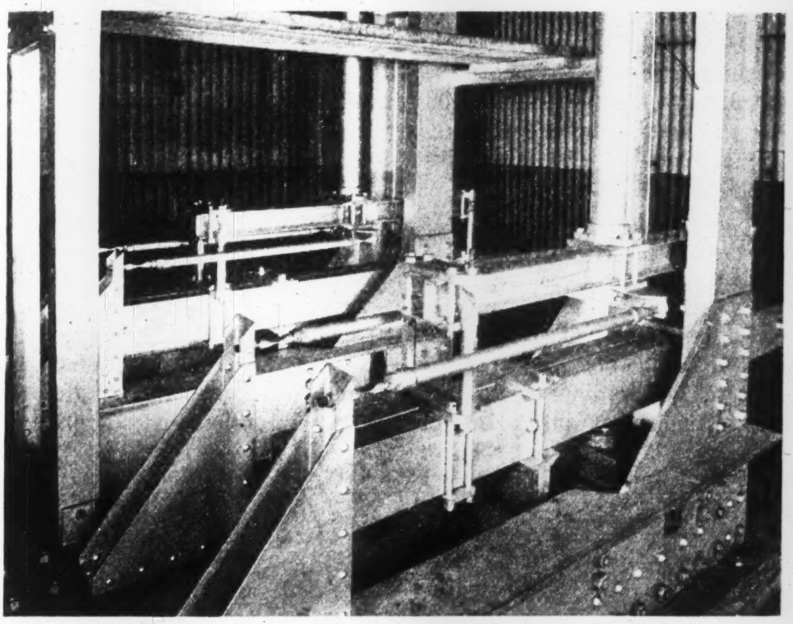

FIG. 5.—Close-Up View Showing Box Girder Specimens Being Tested in Repeated Bending.

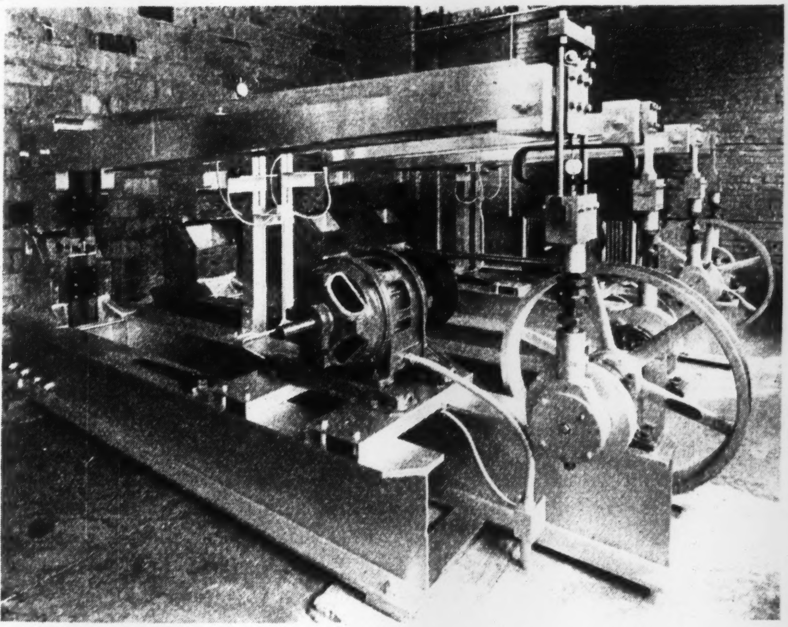

FIG. 6.—High-Speed Fatigue Testing Machine for Joints. Maximum loading range on specimen ± 50,000 lb. Speed 300 or 500 cycles per minute.

ples of units 1 and 2 and the drive of units 3 and 4, were put into operation. These machines, designated as units 5, 6, 7 and 8, have loading beams comparable to those used in the column-beam fatigue machines (50,000-lb. capacity), and have a similar design of drive except that suitable pulleys were provided to give operating speeds of either 300 or 500 cycles per minute. The lower speed is used for the higher load ranges (about one-half to full load capacity), and the higher speed for the lower loads. The nominal maximum width of specimen was increased for these machines as compared to units 1 and 2, as shown in Table I, but the length of specimen was not changed. Each machine is provided with a 25-hp. motor.

TABLE I.—STRUCTURAL FATIGUE TESTING MACHINES.

Unit	Load Capacity, lb.	Loading Beam			Speed, cycles per min.	Motor, hp.	Type of Specimen	Maximum Size of Specimen
		Load on Specimen, lb. per 0.001 in. deflection of upper beam	Actual Lever Ratio	Maximum Movement at Specimen				
Nos. 1 & 2.......	40 000	124.1 122.8	10.079:1 10.071:1	0.3	312	25	Joints	7½ in. wide, 30 in. long
Nos. 3 & 4.......	50 000	194.6 194.6	10:1[a]	0.5	210	15	Columns Simple beams	18 in. square by 6 ft., 8 in. long 6 in. wide, 6 in. deep, 84-in. span
Nos. 5 & 6.......	50 000	184.9 183.6	10.186:1 10.190:1	0.5	300 or 500	25	Joints	16 in. wide, 30 in. long
Nos. 7 & 8.......	50 000	185.1 184.6	10.178:1 10.174:1	0.5	300 or 500	25	Joints	16 in. wide, 30 in. long

[a] Actual ratio not determined. Unnecessary because of calibration method used.

Experience with these different testing machines has demonstrated the merits of the use of oversize motors. Such motors have a considerable flywheel effect which contributes much toward smooth operation, and the excess power insures easy and smooth starting of the machines. The large motors undoubtedly cause some power losses because of the low loads during much of the total running time, but these low loads account, in part at least, for the total absence of motor maintenance troubles. Micro-limit switches are provided so that a change in deflection of a few thousandths of an inch of the loading beam will shut down the machines. In nearly all cases this amount of change in deflection takes place shortly after a fatigue crack occurs in a specimen. Reset revolution counters are geared (100 to 1 reduction) directly to the eccentric shafts of each machine. Removable handwheels are provided for the extension shafts of the motors to facilitate manual operation of the units while adjusting the load ranges on the specimens.

Calibration of the Machines:

A special deflection-measuring device was provided for use in calibrating the upper movable beams of all the units of the machines. This device also serves as a means for checking the loads on the specimens when setting the throw of the eccentrics or shifting the load ranges. As a check on this deflection-measuring device, a permanently installed standard reference bar is provided in the laboratory adjacent to the machines. Readings on the reference bar with the deflection-measuring device indicate whether any changes in the instrument have occurred.

The deflection-measuring device consists essentially of a stiff, lightweight, hollow rectangular beam of suitable length, to one end of which a crosspiece is firmly attached. One end of this crosspiece is provided with a short, pointed support, the other end with a smooth rounded support. The pointed (60 deg.) support is inserted in a small hole drilled in the upper surface near the outer end of one of the pair of loading beams of each unit of the testing machines. The other end of the deflection device is supported on a solid steel roller as shown in Fig. 7, thus providing, with the other supports, a three-point base. Near the middle of the length of the device a dial indicator with a suitable stem extension rests on a crosspiece supported on the loading beams at three points. This crosspiece is provided with pointed and rounded supports with complementary small hole, short V-groove and flat spot on the loading beams of the various units. With these arrangements, easy and accurate application and removal of the deflection-measuring device is assured.

The dial gage indicates deflections directly to 0.001 in. and values can be estimated readily to 0.0002 in. The gage has been calibrated at every tenth division throughout its total travel of 1 in., using standards checked by the National Bureau of Standards. The maximum error throughout the first 0.6 of the dial's range was ±0.0003 in.; for the rest of its range it was ±0.001 in. As normally used the errors in the dial reading are not greater than ±0.0003 in. in deflection, which would correspond to about 60 lb. total load on the specimen. The probable error in reading the dial (0.0002 in.) corresponds to a total load on the specimen of about 40 lb. These two errors, of course, may be additive or partially compensative.

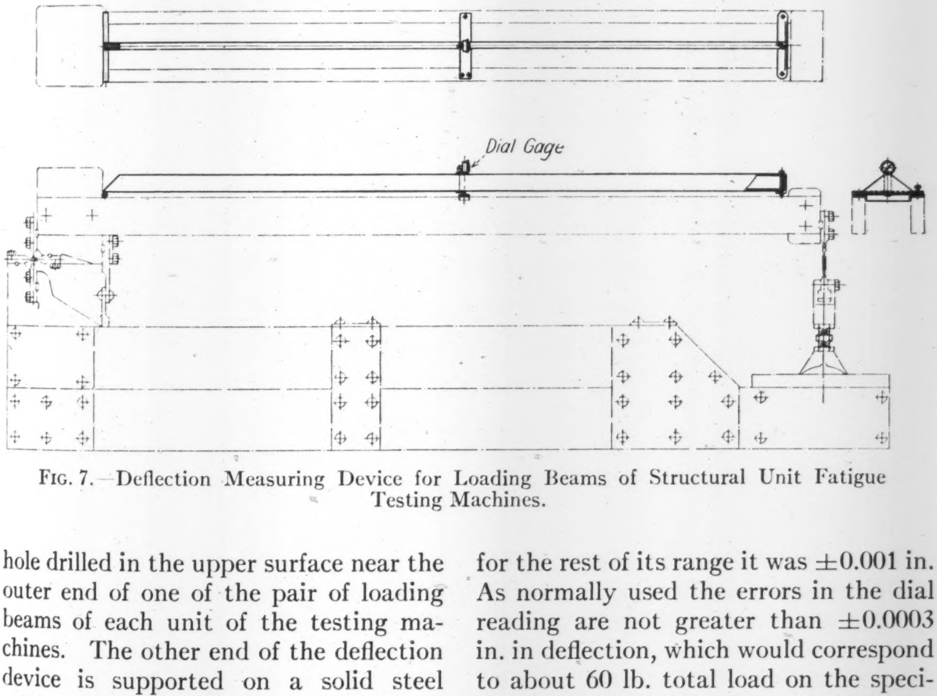

FIG. 7.—Deflection Measuring Device for Loading Beams of Structural Unit Fatigue Testing Machines.

Two different methods were used for checking the loads applied by the machines, but in both methods the loads were determined in terms of the deflection of the upper movable or loading beams of the various units. In the first calibration method used, the deflection reading of the beams was determined without any specimen in the machine; then a dummy specimen was inserted in the machine and loads were applied at the eccentric end of the beams using a calibrated link dynamometer[3] in series with a hydraulic jack. To do this it was necessary to remove the plate fulcrum at the eccentric end of the beam and replace it with a metal plate of suitable thickness so that the center line of action of the load would correspond to the center line of the plate fulcrum. The lever ratios of the loading beams were then carefully determined by actual measurement. From the data thus obtained the loads on the specimens in terms of the deflections of the loading beams of the units were determined as shown in Table I. This procedure was used in the case of units Nos. 1 and 2.

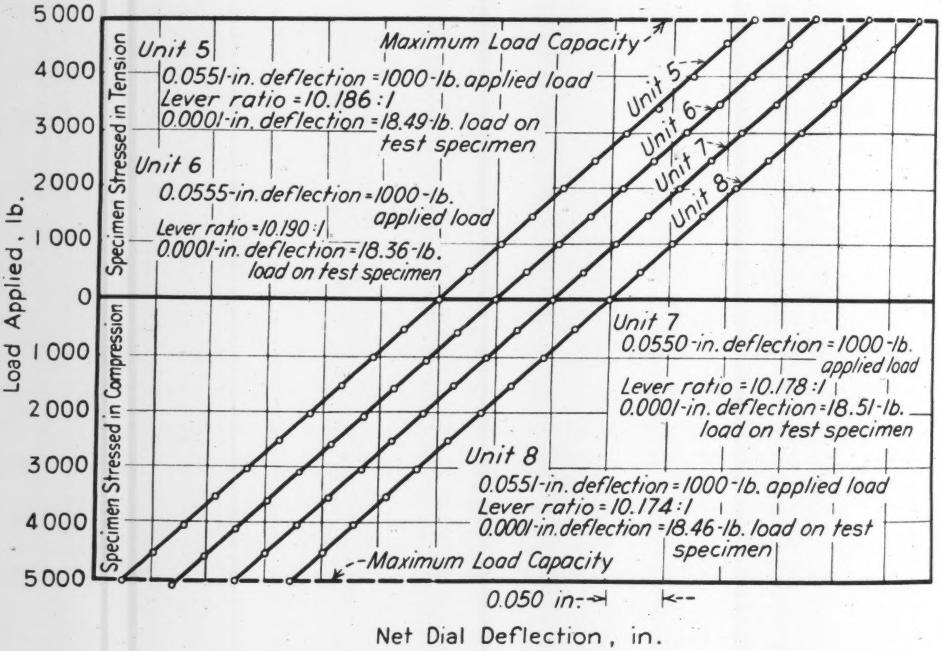

FIG. 8.—Calibration Data for Joint Fatigue Testing Machines Units 5, 6, 7 and 8.

In the case of units Nos. 5, 6, 7 and 8, a modification of this method was used wherein loads were applied to the loading beams, using the apparatus shown in Fig. 6 and the load range adjusting screws of the machine as screw jacks. With this arrangement the beams could be calibrated throughout their total capacity ranges. The calibration data obtained are shown in Fig. 8. The calibration setup is shown in Fig. 6 on the nearest unit of the first machine.

For the column-beam fatigue testing machine a somewhat different calibration procedure was used. In this case calibrated load-weighing devices were installed in the machine in a position corresponding to that of the specimens

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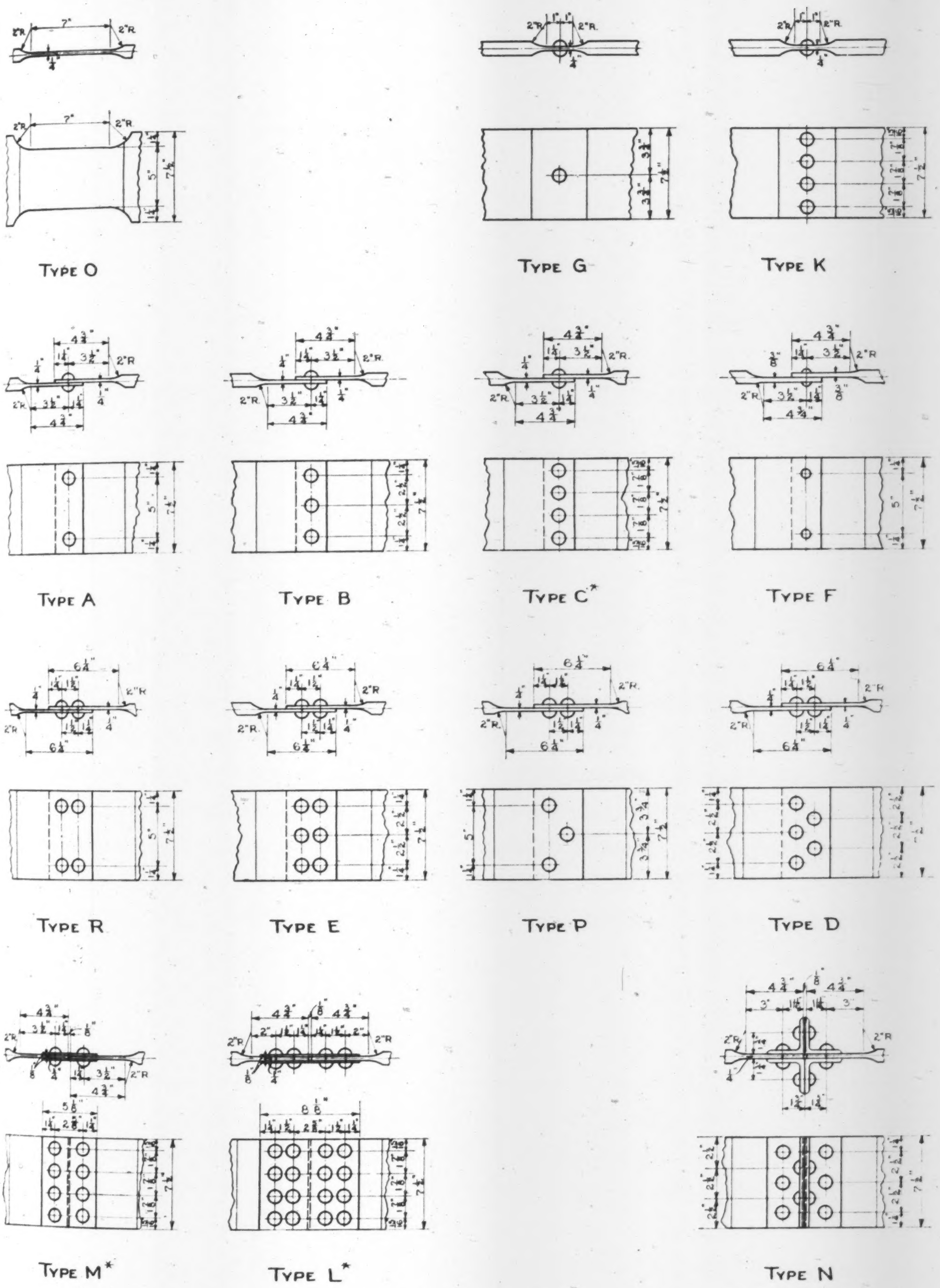
[3] *Laboratory Reports Nos. 6500-289* and *6500-406*, Nat. Bureau Standards. Dynamometer correct within ± 0.2 per cent.



Type O

Type G

Type K

Type A

Type B

Type C*

Type F

Type R

Type E

Type P

Type D

Type M*

Type L*

Type N

FIG. 9.—Details of Some of the Repeated Joint Fatigue Specimens Tested.

being tested. This was accomplished by using a special tubular strut and adaptors so arranged that Amsler boxes[4] of suitable capacity could be loaded in both tension and compression and the corresponding deflections of the loading beams determined in terms of the loads indicated by the boxes. Loads on the beams were applied by displacement of their eccentric ends. As in the case of the other units using the method previously described, straight-line calibration relationships between load and deflection of the beams were obtained.

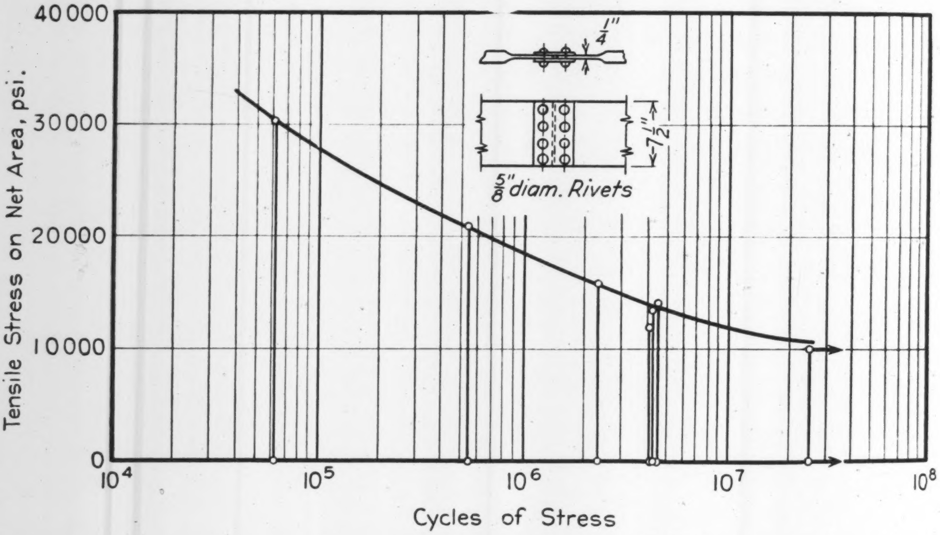


FIG. 10.—Fatigue Results from Repeated Joints Fabricated from 17S-T Plates and 17S-T Rivets. Nominal stress on net area varied from zero to values indicated.

In a study of inertia effects upon the loading of specimens, it has been found that the magnitude of the effect is dependent upon two factors: (1) the amplitude of the outer end of the loading beam, and (2) the speed of the machine. For most of the tests which have been made, this effect does not exceed 5 per cent, and at the endurance limits obtained the effect is much less.

Results Obtained with the Machines:

The first of the fatigue testing machines described has now been in operation almost continuously for four years, a brief interruption occurring during the time required to change the speed and capacity of the machine. Two plate fulcra have failed in fatigue in the column-beam testing machine because as originally designed the stresses used were too high. This has been corrected quite satisfactorily by reducing the thickness and increasing the length of the reduced section of the plates slightly. These plate fulcra are all made from silicon-vanadium alloy steel, heat treated so as to give high fatigue strength. One of the aluminum alloy loading beams in the initial machine failed in fatigue because of overloading beyond its designed capacity. Some of the ball bearings have been replaced recently in the first machine, but these bearings were known to be overloaded somewhat after the capacity of the machine was increased. It was much cheaper to replace the bearings every two or three years than to rebuild the machine so as to provide for larger bearings. All of the machines with the exception of the first one operate very smoothly and quietly. The first machine has a noisy coupling in it and some noise comes from the geared motor unit.

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[4] *Laboratory Reports Nos. 6500-238* and *6500-239*, Nat. Bureau Standards. Devices correct within ± 0.2 per cent.

Numerous types of specimens have been tested in the machines. Some of these types are shown in Fig. 9. In all, about 400 specimens have been tested previous to the first of this year. In general, the tests have shown such a very marked consistency throughout that only a few check tests have been necessary. Some typical data are shown in Fig. 10. It is not the purpose of this paper to discuss the fatigue values or design of structural units to improve their fatigue strengths. It may be stated, however, that these testing machines have proved very useful in defining the fatigue strength of structural units such as joints, struts and beams, and have given results indicating design changes that should be made in structures to increase their fatigue strengths.

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DISCUSSION

Mr. J. M. Lessells[1] (presented in written form).—This paper is a very welcome contribution to the mechanics of fatigue testing, and it is to be hoped that the author will see fit to publish more of his results at some future date. It has been the writer's privilege to see these machines in operation, and he cannot speak too highly of the care taken in design details so as to give very nice operation equipment.

In general, most of our knowledge of fatigue depends largely on tests conducted with zero mean stress during the cycle due to the ease in making such tests. While certain data are available for stress cycles with positive mean stress and a lesser amount for negative mean stress, it is true that the effect of mean stress has yet to be fully explored. This information is badly needed in order to throw further light on the effect of mean stress, especially if these are compressive. Does the Goodman relation hold for such conditions as well as it seems to hold for tensile mean stresses?

The development of the pulsator type of machine has resulted in more data becoming available, especially in Europe, and in particular in Germany. Because this development involves testing machines which can be employed in other work, it is expected that the additions to the knowledge will be slow. In the machines developed by Templin, this defect is largely removed and consequently the machines can be devoted exclusively to the fatigue testing of all kinds of structures under different mean stresses.

It is therefore to be hoped that more results will be published, because, from what has been made available from the pulsator type and also from the special machines developed by F. C. Lea in England, there is evidence that the range of stress continues to increase, or at least not decrease, when the mean stresses have a negative value during the cycle.

Mr. W. L. Howland.[2]—I would like to ask Mr. Templin how he will present the data secured with the large-size testing machine so that they will be useful to the engineer.

Mr. R. L. Templin[3] (*author's closure*).—In some ways the results are qualitative and in others we believe they are quantitative. An example of the former, and one which should be useful to design engineers, is that open holes in structures subjected to repeated loads are more detrimental to the life of the structure than holes containing properly driven rivets. Examples of the quantitative results covering such important items as the best proportions of joints, and the relative importance of shear stress, tensile stress, and bearing stress will all be presented in detail when the data are sufficiently complete.

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[1] Associate Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

[2] Assistant Director of Research, Guggenheim Aeronautics Laboratory, California Institute of Technology, Pasadena, Calif.

[3] Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pa.

FATIGUE STRENGTH OF MACHINED FORGINGS 6 TO 7 IN. IN DIAMETER

BY O. J. HORGER[1] AND H. R. NEIFERT[1]

SYNOPSIS

The Association of American Railroads is making extensive laboratory tests to determine the fatigue strength of full-size railroad car axles and this paper forms a progress report on some of this work. Discusses rotating cantilever beam fatigue tests made on 31 steel forgings from the same heat of S.A.E. No. 1045 steel machined to a tapered test section having a diameter of 6 to 7 in. These specimens were tested in the as-forged condition without heat treatment but machined after forging to a smooth turned surface.

Data is included on scale-size fatigue tests of $1\frac{1}{2}$ and 0.3-in. diameter specimens. Metallurgical studies and profilograph records of surface finish supplement the fatigue tests. A discussion of test results with reference to those of previous investigators is also given.

The Association of American Railroads is conducting laboratory fatigue tests on full-size passenger-car axles.[2] This project is under the direction of an A.A.R. committee, assisted by the technical committee of the Association of American Steel Manufacturers, all of which is under the supervision of the committee chairman, W. I. Cantley, Mechanical Engineer for the A.A.R. The fatigue tests are being made at Canton, Ohio.

This paper reports findings on the body of car axles which may be considered as plain specimens 6 to 7 in. in diameter; that is, the shape of the body is such that there is no stress concentration due to shape. These findings are of secondary nature in that the primary object of these tests was to determine the fatigue strength of these axles at the section where the wheel is pressed on, results of which are not given here. The reported data refer to the fatigue strength of the body of the axle, which is the portion connecting the wheel seats. The full-size axles as tested represent design, material, manufacturing processes, and machining conditions as found in railroad practice. In fact the axles in the as-tested condition could be applied to a railroad car without modification, so that the test results represent what may be expected from conditions prevailing in service.

MATERIAL

Specification:

The material used for both the full-size axles and auxiliary tests is according to A.A.R. specifications for axles M-101-36, grade B, and was produced from one heat of basic open-hearth steel. Chemical and physical properties were obtained from drillings and tension specimens from the ends of full-size axles as shown in Table I. Carbon determinations were made on each axle but random check analysis was made for other elements given in the table.

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[1] In Charge of Railway Engineering and Research, and Engineer, Research Laboratory, respectively, The Timken Roller Bearing Co., Canton, Ohio.

[2] "Passenger Car Axle Tests, $5\frac{1}{2} \times 10$-in. Journals," First and Second Progress Reports, Assn. Am. Railroads, Chicago, Ill., May and November, 1938.

In general, the heat is representative of average axle practice, except for effort to confine the axles to a carbon content about half way between the specification minimum of 0.40 per cent and maximum of 0.55 per cent.

TABLE I.

	Center	Midway	Outside
Chemical Composition:			
Carbon, per cent	0.36 to 0.50	0.38 to 0.49	0.41 to 0.49
Manganese, per cent	....	0.57	....
Phosphorous, per cent	....	0.014	....
Sulfur, per cent	....	0.027	....
Silicon, per cent	....	0.24	....
Physical Properties:			
Yield strength, psi.[a]	....	42 000 to 63 000	42 500 to 64 000
Tensile strength, psi	....	84 500 to 97 500	87 500 to 95 000
Reduction of area, per cent	....	14.1 to 32.1	34.4 to 41.0
Elongation, per cent	....	12.5 to 21.0	19.5 to 25.0
Brinell hardness	187 to 197	192 to 197	187 to 197
Izod impact	....	6 to 18	9 to 16

[a] Determined by "drop of the beam" method.

Rolling and Forging Procedure:

All ingots for full-size axles were bloomed in a 44-in., 2-high electrically driven reversing mill, sixteen to eighteen passes being required to reduce the ingots to 9 by 9-in., and 10 by 10-in. blooms. The blooms were then reheated to 2230 to 2380 F. and rolled into $7\frac{1}{2}$-in. rounds or $8\frac{1}{8}$-in. octagons, depending upon wheel seat diameter. From the rolling mill they were transferred within 15 sec. to 2 min. to the forging hammers, where the body was forged down to the proper shape. The temperature of the various axles before forging varied from 1760 to 1960 F. and after forging the temperature was 1590 to 1820 F. The axles were then hot-straightened by either (*a*) rolling the axle with bearings on the wheel seat and center simultaneously or (*b*) by means of a forging hammer.

The $1\frac{1}{2}$-in. diameter plain specimens were machined from $2\frac{1}{4}$-in. diameter hot-rolled bar stock of the same specification as the full-size axles. One ingot of the heat mentioned before was bloomed in the billet mill to 5 by 5 in. in 13 passes, and then reduced to $2\frac{1}{4}$ in. round in the merchant mill in nine passes.

All axles were tested in the as-forged or as-rolled condition after being machined and no heat treatment was used.

Machining Procedure:

The body portion of the full-size forged axles was machined as designated below by roughing and finishing operations using the following approximate lathe conditions:

	Rough Turn	Finish Turn
Number of cuts	2	1
Depth of each cut, in.	1st—$\frac{3}{16}$ max. 2nd—$\frac{3}{16}$ max.	$\frac{1}{8}$
Revolutions per minute	16	24
Feed per revolution, in.	$\frac{1}{16}$	$\frac{1}{16}$

Water coolant was used in the finish operation giving what is termed "pullman finish." No lubricant or coolant was used on the roughing cuts. All axles were carefully inspected for seams or checks which might be revealed in turning, but none were found.

The $1\frac{1}{2}$-in. diameter specimen was machined from 15-in. lengths of $2\frac{1}{4}$-in. diameter hot-rolled stock. The total thickness of stock removed at the critical section was approximately $\frac{3}{8}$ in.

section is that used in standard design practice in car axles.

Six of the full-size axles were surface rolled in the body over the finish-turned surface previously mentioned with 10-in. diameter by 5-in. radius contour rollers at a pressure of 25,000 lb. per roller.[3] This was done to prevent fatigue failure in the body at high bending stresses and to force fatigue failure in the axle where the wheel was pressed on. The body of all other axles was left in the as-received finish-turned condition already described.

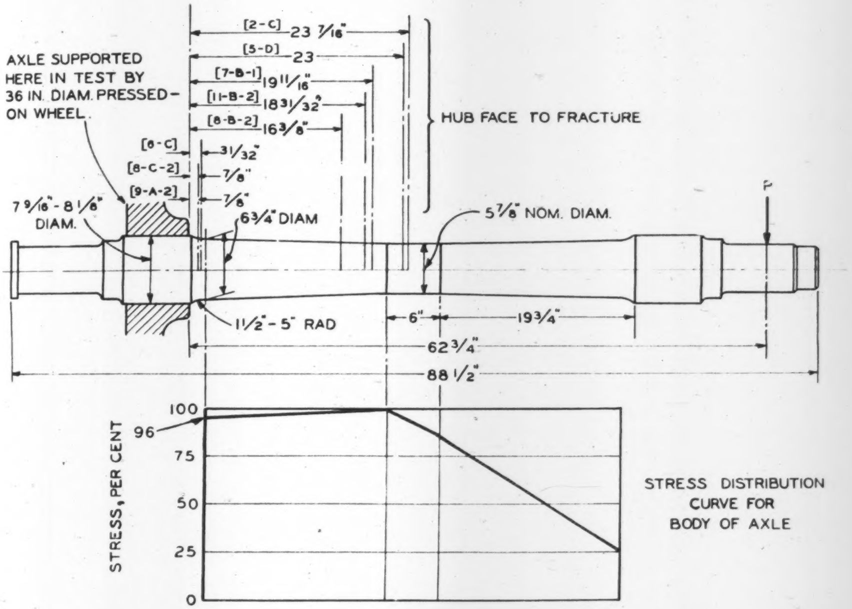
[2-C] 23 7/16"
[5-D] 23
[7-B-1] 19 11/16"
[11-B-2] 18 31/32"
[8-B-2] 16 3/8"
HUB FACE TO FRACTURE
AXLE SUPPORTED HERE IN TEST BY 36 IN. DIAM. PRESSED-ON WHEEL.
[6-C] 31/32"
[8-C-2] 7/8"
[9-A-2] 7/8"
7 9/16"-8 1/8" DIAM.
6 3/4" DIAM
5 7/8" NOM. DIAM.
P
1 1/2"-5" RAD
6"
19 3/4"
62 3/4"
88 1/2"
100
96
75
50
25
0
STRESS, PER CENT
STRESS DISTRIBUTION CURVE FOR BODY OF AXLE

FIG. 1.—Full-Size Test Axle. Showing detail of axle design and location of body fractures with test axle numbers.

SPECIMENS TESTED

Full-Size Axles:

Design of the full-size axle specimen is shown in Fig. 1. A wheel is press fitted on one end of the axle as indicated, which also serves as a means of attaching the axle to the testing machine. The test load *P* is applied at the opposite end of the axle. The stress distribution curve for the body of the axle indicates the distribution of maximum calculated bending stress along the length of the test section. The shape of this test

$1\frac{1}{2}$-in. Axles:

Auxiliary fatigue tests were made on $1\frac{1}{2}$-in. diameter specimens of the design shown in Fig. 8. These were machined from $2\frac{1}{4}$-in. diameter hot-rolled bar stock of the same specification as the full-size axles. A wheel press fitted on one end of the specimen serves to attach the axle to the testing machine. The test load is applied at P. The test section of the specimen is smooth turned, but not polished. Point of maximum bending stress, or critical section, is at the $1\frac{1}{2}$-in. diameter indicated in Fig. 8 and the stress drops off a little less than 1 per cent at the ends of the tapered section adjoining the 3-in. fillets.

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[3] This rolling procedure is described in detail in a paper by T. V. Buckwalter, O. J. Horger and W. C. Sanders, "Modern Locomotive and Axle Testing Equipment," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 59, No. 3, April, 1937, p. 225.

0.3-in. Specimens:

R. R. Moore rotating beam specimens 0.3 in. in diameter were machined from one of the full-size axles at the wheel seat.[4] The cross-sectional position from which these specimens were selected is shown in Fig. 9. Test section radius of specimens was $9\frac{7}{8}$ in. and was polished.

TESTING MACHINES

Full-Size Tests:

Fatigue machines used to test the full-size axles are of the cantilever type shown in Fig. 2. The design of this machine is symmetrical so that two axles may be tested simultaneously at the same or different bending stresses, one test axle being located at each end of the machine. Constant vertical spring load is applied through knife edges at the journal end of the axle opposite the axle end on which the wheel is mounted. Several combinations of loading springs are provided having low spring constant so that any eccentricity of the loading end of the axle or vibrations will cause

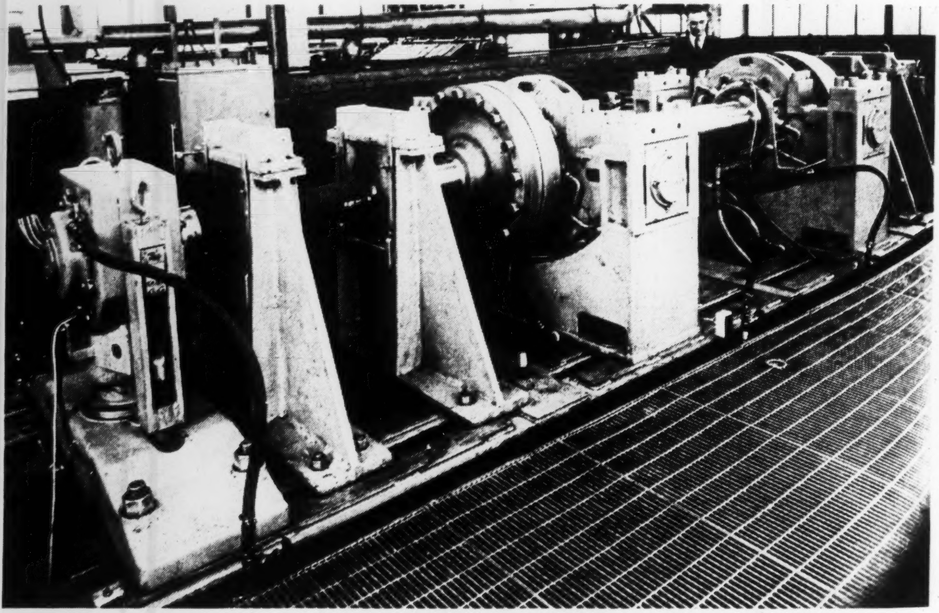

FIG. 2.—Full-Size A.A.R. Axle Fatigue Testing Machine Shown with Test Axle in Position on Each End of the Machine and Being Tested as Cantilever Beams. Two such machines are being operated by the A.A.R. in this laboratory.

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[4] Unpublished tests on 0.3-in. specimens made at University of Michigan.

relatively small change in axle bending stress.

A 36-in. diameter wheel is pressed on the test axle near one end and this entire axle and wheel assembly is bolted to the rotating flange of the testing machine by means of 34 bolts at the rim of the wheel. The journal end of the axle protruding beyond the pressed-on wheel projects into the hollow bore of the test machine spindle, and there is no contact between spindle and test axle and wheel assembly except at the bolted rim of the wheel. A 75-hp. variable speed motor drives the machine at a maximum speed of 1450 to 1500 r.p.m. which is equivalent to 155 to 160 m.p.h. on 36-in. diameter car wheels. All tests were made at the maximum speed of the test machines.

The roller bearings supporting the main driver spindle are mounted in pivot-supported housings which have circulating well water passing through cored chambers in the cast housings and closures. These bearings are lubricated by means of a pressure oil system from a 1000-gal. water-cooled tank which provides a continuous flow of circulating oil. The loading bearings through which load is applied on the end of the axle are also mounted in boxes which are cooled by circulating water but the oil does not circulate.

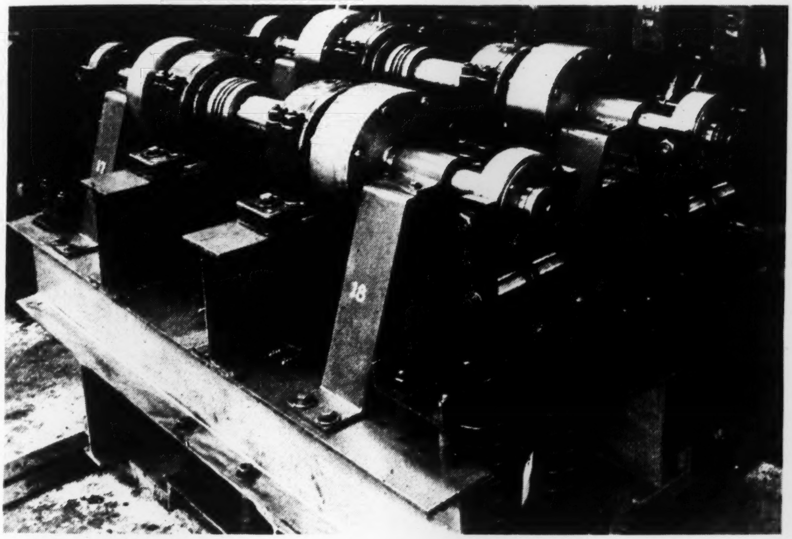


FIG. 3.—Scale Size Axle Fatigue Testing Machine Shown with Test Axles in Position at Each End of the Machine and Being Tested as Cantilever Beams. Seven machines of this type are available.

$1\frac{1}{2}$-in Tests:

Plain specimens $1\frac{1}{2}$ in. in diameter were also tested in machines of the double-end cantilever type similar in design to the large machines as shown in Fig. 3. A 5-hp. constant-speed motor is used to drive each machine. The speed of the several machines in which these specimens were tested ranges from 1400 to 2100 r.p.m. which is equivalent to 150 to 225 m.p.h., respectively, on 36-in. diameter wheels.

Bending stress values given throughout this paper are calculated by the elementary beam formula:

$$S = \frac{PL}{Z}$$

where S = stress at outer fiber,
P = load on end of test axle,
L = length of lever arm, and
Z = section modulus.

The endurance limit is based on 168 million revolutions which is equivalent to 300,000 miles in car service on 36-in. diameter wheels, with the exception of the 0.3-in. specimens for which the usual 10 million stress reversals was used.

SURFACE FINISH

A practice is usually followed in this laboratory of obtaining a permanent graphical record giving a measurement of the irregularities of surface finish on each specimen tested. Typical profilograph records of several turned finishes showing the height of tool marks are shown in Fig. 5 for both the full-size and $1\frac{1}{2}$-in. diameter specimens. Surface conditions shown in Fig. 5 (*a*) and (*b*) form the basis of this paper but that shown in Fig. 5 (*c*) indicates a type of surface still under investigation and later commented upon in the discussion.

TABLE II.—DATA ON BODY FAILURES OF FULL-SIZE AXLES.

Axle	Calculated Bending Stress at Fracture, psi.	Description of Failure
No. 7-B-1	26 400	Broke off in tapered section
No. 5-D	26 100	Broke off in center section
No. 9-A-2	25 800	Cracked 3 deg. up fillet
No. 11-B-2	25 100	Broke off in tapered section
No. 8-B-2	24 500	Broke off in tapered section
No. 6-C	24 300	Broke off 17 deg. up fillet
No. 8-C-2	22 900	Broke off 7 deg. up fillet
No. 2-C	18 300	Broke off in center section

NOTE.—When failure occurred in fillet, stress is calculated for actual diameter at base of fillet. When failure occurred in tapered or center section stress is given for actual diameter at failure.

The full-size axles were shipped to our laboratory in the finish turned condition and when received presented a slightly rusted condition in the body of the axle which was not disturbed at the time of the fatigue test. Figure 6 shows a typical photograph of this surface indicating the presence of slight pitting, and this is a condition which may be found present to a more or less

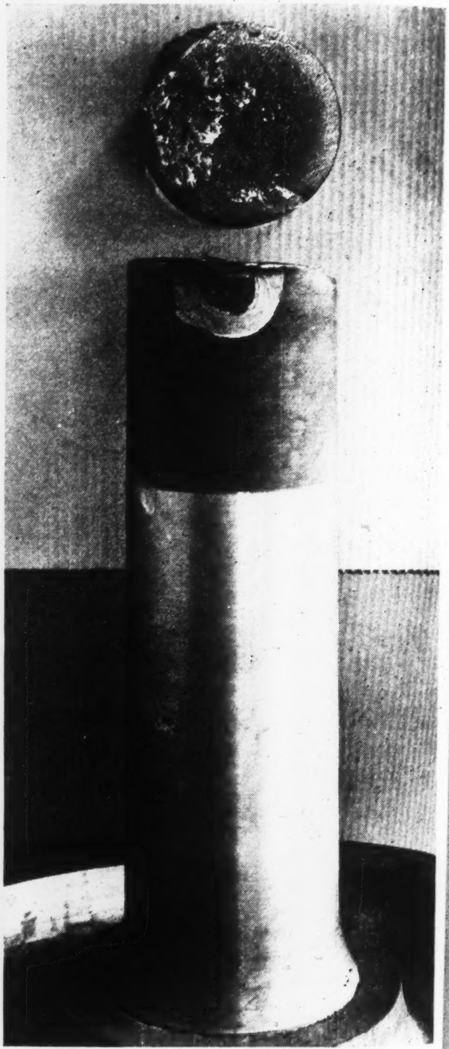
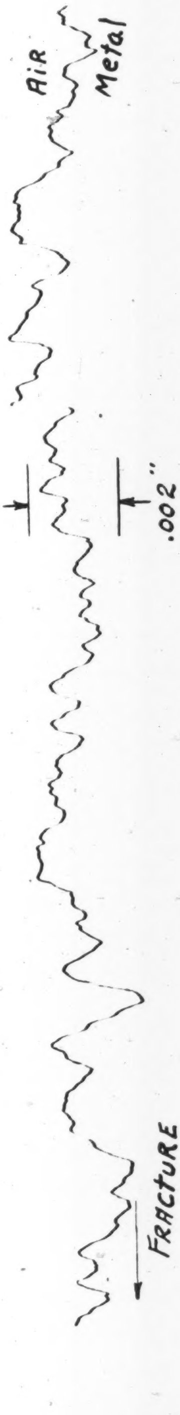
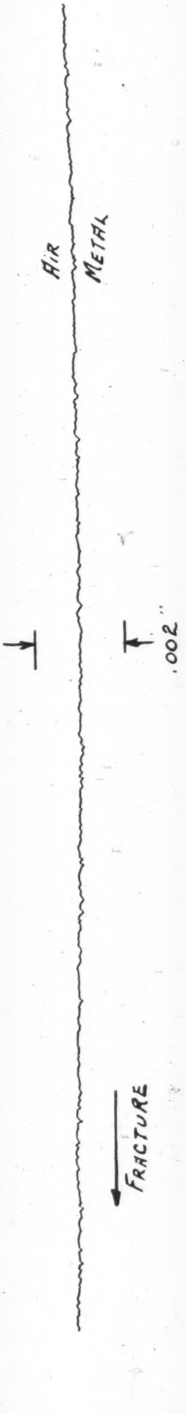


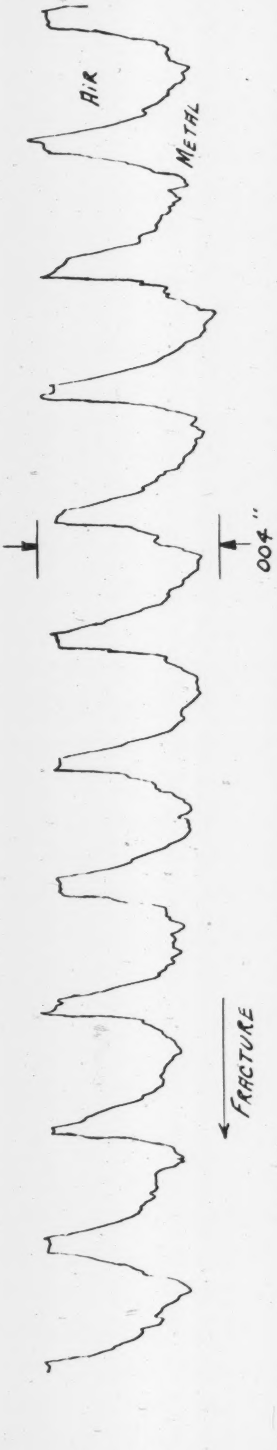
FIG. 4.—Typical Body Failure of Full-Size Axle. Axle No. 5-D.



(a) Full-size axle No. 3-D—smooth turned finish ("Pullman finish").



(b) 1½-in. diameter axle No. 26D5-11—smooth turned finish.



(c) 1½-in. diameter axle No. 26B5-7—rough turned finish.

FIG. 5.—Profilograph Records of Surface Finish Test Section of Various Specimens Tested (vertical, × 250; horizontal, × 30).

degree on axles operating in service. Other portions of the axle such as the wheel seat, which was the principal section being investigated, was machined after the axles were received, but these results are not reported in this paper.

RESULTS OF TESTS

A total of 31 full-size axles were tested of which 8 developed fatigue failures in the body. Figure 1 shows the location of these failures and Fig. 4 a typical fatigue failure in the body of the axle, while Table II lists the calculated bending stress at the plane of fracture. The *S-N* curve is shown in Fig. 7 and indicates an endurance limit of 17,500 psi. Round solid points in Fig. 7 representing failed axles show the calculated stress at the fracture, this stress being less than the maximum stress in the body of the axle because none of the failures occurred exactly at the cross-section of maximum stress. Both hollow round and square points representing axles which did not fail show the maximum stress in the body of the axle in accordance with the curve of bending stress distribution along the length of the axle indicated in Fig. 1. Axles which were surface-rolled in the body are indicated by square points on the *S-N* curve. None of these axles showed fatigue failure. Due to an insufficient number of tests a determination of the endurance limit was not possible.

TABLE III.—DATA ON 1½-IN. DIAMETER SPECIMENS.

Specimen	Calculated Bending Stress at Fracture, psi.	Results of Test
No. 26D5-11 ...	37 100	Broke off up fillet 2 deg.
No. 26D5- 8 ...	34 900	Broke off in tapered section
No. 26B5- 3....	32 000	Not cracked
No. 26D5- 9 ...	31 900	Broke off in tapered section
No. 26D5- 5 ...	30 100	Broke off in tapered section
No. 26D5- 7 ...	30 000	Not cracked
No. 26D5- 4 ...	29 700	Broke off at base of fillet
No. 26D5- 2 ...	29 200	Broke off in tapered section
No. 26B5- 2....	27 000	Not cracked
No. 26D5-10 ...	25 000	Not cracked
No. 26B5- 1....	24 100	Not cracked
No. 26B5- 4....	23 800	Not cracked

NOTE.—When failure occurred in fillet, stress is calculated for actual diameter at base of fillet. When failure occurred in tapered section stress is given for actual diameter at failure. When no failure occurred, stress is given for 1½- in. diameter critical section.

1½-in. Tests:

The *S-N* curve showing the results of tests made on 12 of the 1½-in. diameter specimens is given in Fig. 8 from tabulated data in Table III. This curve indicates an endurance limit strength of 28,000 psi. for the smooth-turned specimen which is about 60 per cent higher than that obtained for the body of the full-size axles in Fig. 7. The points representing broken specimens show the calculated bending stress at the fracture, while points representing not broken specimens show the maximum stress which occurs at the 1½-in. diameter cross-section.

0.3-in. Tests:

Results of these tests are plotted in the *S-N* curve of Fig. 9 and an endurance limit of 33,000 psi. was selected for the outer specimens.

DISCUSSION OF TEST RESULTS

Full-Size Axles:

One is impressed by the great scatter in test results plotted in Fig. 7. While a safe endurance limit of 17,500 psi. is established, there is no definite satisfaction that further tests may not show greater scatter. It would appear as though 25,000 psi. could be considered as a possible maximum endurance limit as established by the large number of axles which did not fail at about this stress or below. The question naturally arises as to the reason for such a low fatigue strength and resultant scatter. No definite conclusions are believed justified at this time but several individual factors or combinations thereof

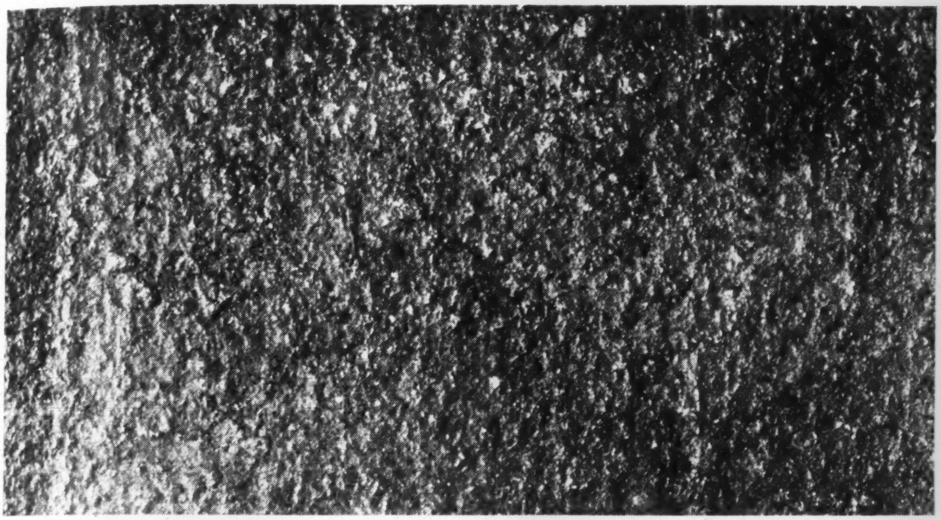


FIG. 6.—Rusted Surface of Body of Full-Size Axle No. 11-B-2 Showing Pitted Condition (× 8).

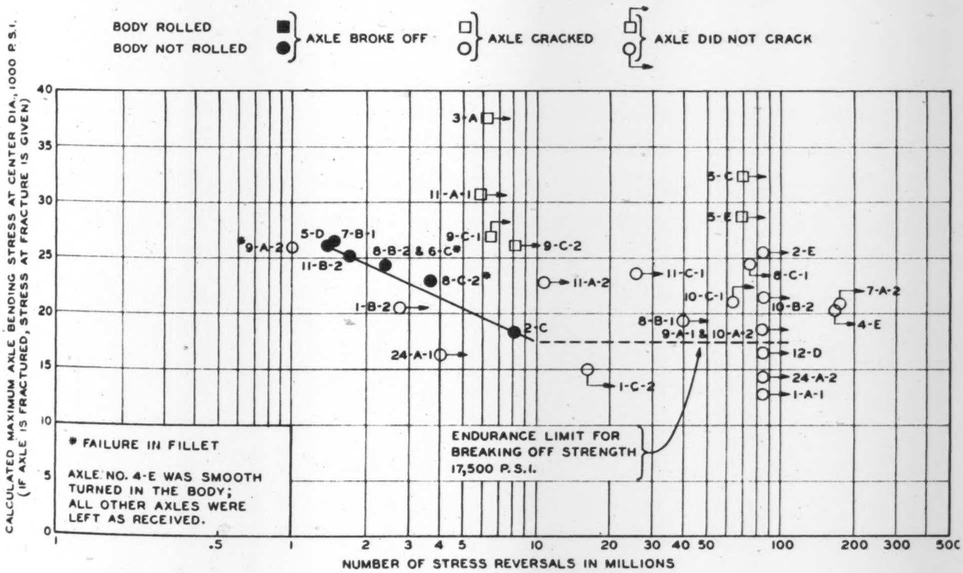


FIG. 7.—*S-N* Curve for 6 to 7-in. Diameter Plain Specimens.

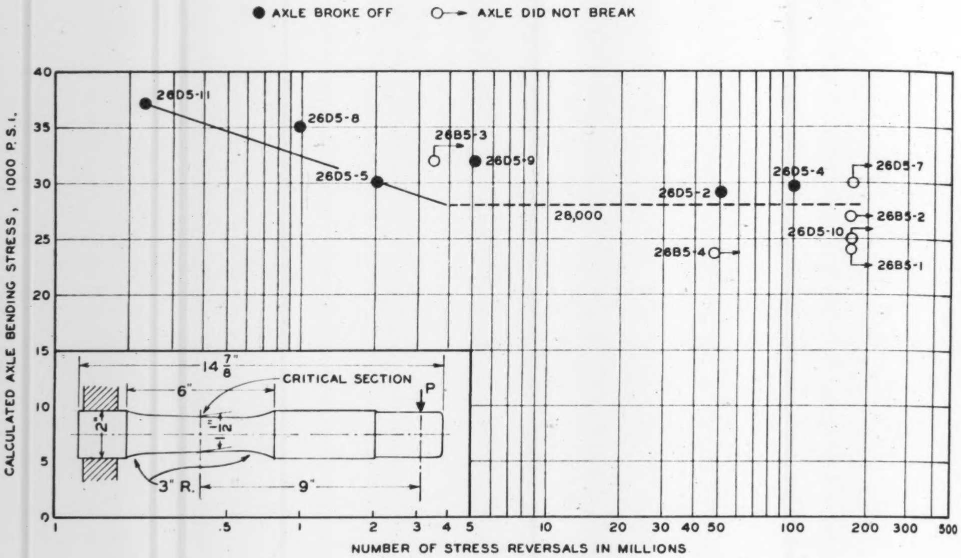


FIG. 8.—*S-N* Curve for 1½-in. Diameter Plain Specimens—Smooth Turned Surface.

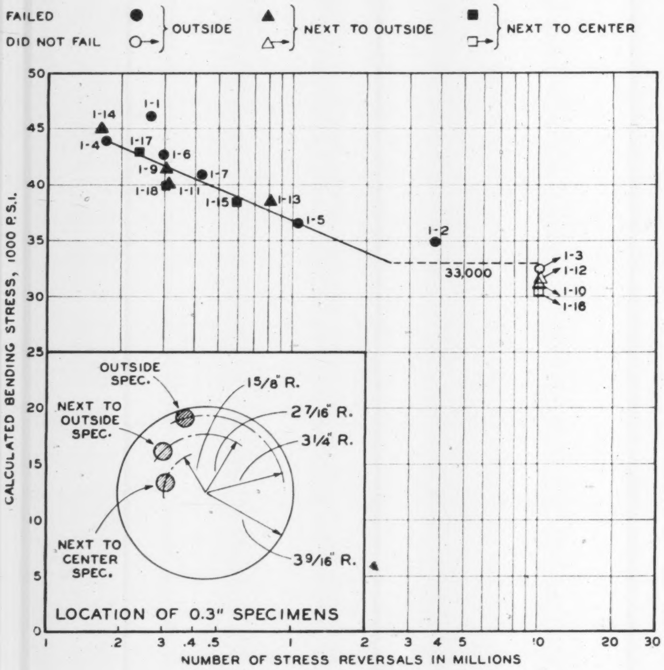
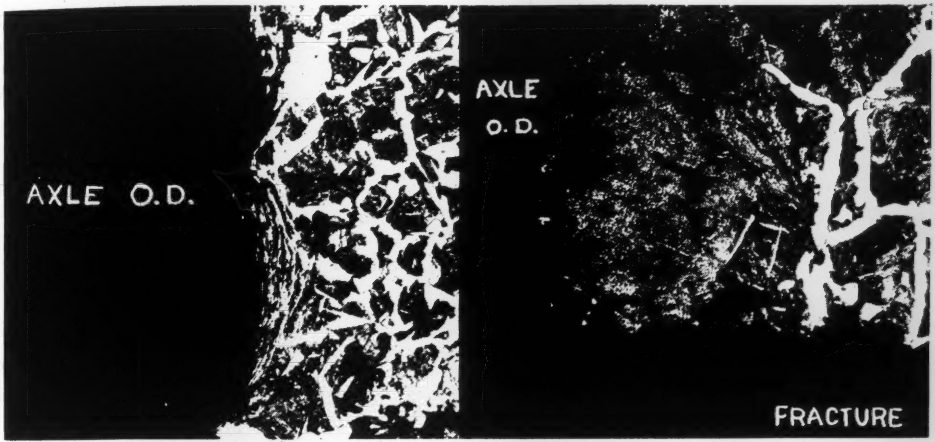


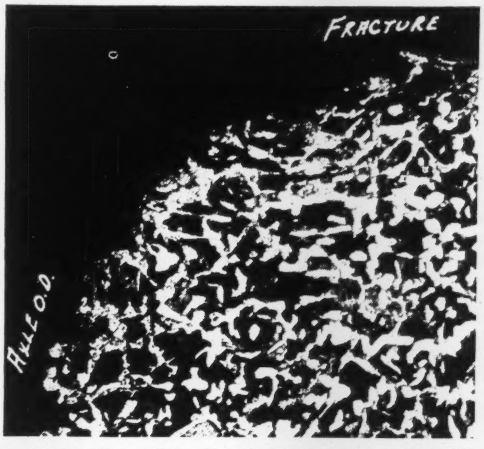
FIG. 9.—*S-N* Curve for 0.300-in. Diameter Fatigue Specimens.

which may have some influence are conditions of (1) grain size, (2) forging, (3) surface, and (4) testing temperature, which will be discussed in this order.



(a) Axle No. 2-C. Sample taken $\frac{9}{16}$ in. from body fracture.

(b) Axle No. 2-C. Sample taken at corner of outside diameter and body fracture. McQuaid-Ehn grain size $^4/_5$.



(c) Axle No. 11-B-2. Sample taken at corner of outside diameter and body fracture.

FIG. 10.—Photomicrographic Studies of Longitudinal Sections of Full-Size Axles (× 100).

One may reasonably expect considerable variation in grain size throughout any one axle as a result of no heat treatment after forging. Photomicrographs are made from each axle tested as routine examination and results typical of a large number of studies reflect the expectations shown in Fig. 10 where the pearlite grains are enclosed in defined envelopes of ferrite. A wide variation in structural conditions is shown between Fig. 10 (*a*) and (*b*) as it exists in the same axle and that fatigue failure developed through a section in Fig. 10 (*b*) where grain coarseness exists. Cazaud[5] showed for a mild carbon steel that the endurance limit could be decreased by a value up to about 20 per cent by somewhat similar structural variations. Dorey[6] also reported on service fractures of marine equipment showing unfavorable structural conditions existing in the region of failure, but he did not state what decreased strength is obtained by such unfavorable structural conditions. In these axle tests, however, all eight failed axles did not fracture through a region of the most coarse structure as is evidenced in Fig. 10 (*c*). The plane of fracture would be determined by a combination of the least favorable structural condition existing in relation to its position along the length of axle and the variable bending stress shown in Fig. 1.

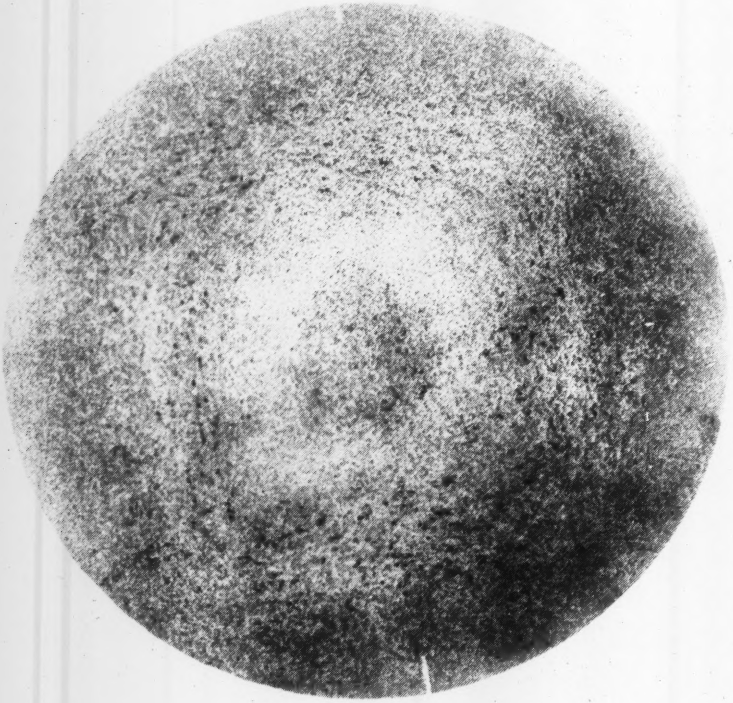


FIG. 11.—Photomacrograph of Axle No. 10-C-1 Taken at Plane of Maximum Body Stress (× $\frac{5}{8}$).

Etched in 50 per cent hydrochloric acid for 45 min. (Two diametrically opposite short lines are artificial marks used for identification purposes.)

Forging operations under some conditions may produce directional properties of the grains or unfavorable structural characteristics. Aitchison and Johnson[7] investigated directional properties of various steel forgings and found that there is not such a large difference between the fatigue strength of the steel as determined from specimens selected parallel and across the grain; the maximum difference found was less than 20 per cent. Also, The Research Institute of the Vereinigte Stahlwerks, as reported by Dorey,[6] selected specimens parallel and across the grain from crank sections of large marine engine crankshafts and found the fatigue strength of specimens across the grain 25 per cent less than parallel with the grain. Results of these investigations showed that the tensile and yield strength is little affected by directional properties but that ductility and impact strength are much reduced. Investigations made on these test axles have not been concluded as to the existence of directional characteristics as indicated by such mechanical properties aided by sulfur prints and etching to detect outcropping of flow lines to the surface of the forging.[8] Some transverse macro etch studies have disclosed the presence of an ingot pattern shown in Fig. 11. It is important to note, however, that Fig. 11 represents a condition at a section of the center of the axle which did not cause failure at a bending stress of 21,200 psi. for 53,250,000 revolutions. Presence of this characteristic was the exception and was found only on several axles that failed and not apparent on all of the failed axles. It would be interesting to test a group of axles having an ingot pattern similar to Fig. 11 with the object of determining whether fatigue fracture originated at the corner of the pattern and also whether the endurance limit was influenced by such conditions.

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[5] R. Cazaud and L. Persoz, "La Fatigue des Métaux," Dunod, Paris (1937).

[6] S. F. Dorey, "Marine Machinery Defects—Their Causes and Prevention," *Transactions*, Inst. Marine Engrs., Vol. XLVII, Part 12, pp. 1-79 (1935).

[7] L. Aitchison and L. W. Johnson, "The Effect of Grain upon the Fatigue Strength of Steels," *Journal*, Iron and Steel Inst. (British), Vol. CXI, No. 1, pp. 351-378 (1925).

It would appear very questionable whether sufficient variation in the turned surface finish as shown in Fig. 5 (*a*) would exist from one axle to another to cause this scatter. Several investigators[9, 10, 11] have shown that for specimens up to about 1 in. in diameter, the turned finish shows as much as 20 per cent decreased endurance limit over that obtained for a polished surface.

Previous rusted surface condition of the bodies of the axles as shown in Fig. 6 may be considered as a basis of explaining the reduced fatigue strength and scatter. McAdam and Clyne[12] made fatigue tests on specimens which had been previously submitted to stressless corrosion; they found that the initial corrosion pits formed equivalent mechanical notches serving to reduce the endurance limit below that of a smooth surface by a value dependent upon the severity or number of days of stressless corrosion treatment. Using steel having a tensile strength of 100,000 psi., they found a maximum reduction of 35 per cent in the endurance limit. Unless the failed axles included in the region of scatter in the *S-N* curve of Fig. 7 were subject to a condition of stressless corrosion to a greater degree than similar unfailed axles it would appear as though this explanation would not be logical.

In the process of fatigue testing of plain specimens 1 and 2 in. in diameter, it has been found[13, 14] that above the endurance limit sufficient heat was developed in the specimen to temper color it. At the endurance limit, however, the temperature was not sufficient to discolor so that temperature was not considered as a factor in determining the endurance limit. As the size of the specimen increases, the volume of material producing the heat increases as the square of the diameter, while the radiating surface increases at a slower rate proportional to the diameter. Therefore with large-diameter axles, such as reported on here, there may be some question as to heating produced in the specimen and its influence on the test values. It may be said that no axles showed visual evidence of this heat, and the hand could be held comfortably on any test axle. This absence of heat may be explained by the design of the machine with both water-cooled chambers and lubricator system as previously described. No measurement has been made of the actual heat dissipated in these tests.

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[8] Unpublished data by T. D. Sedwick, Engineer of Tests, Chicago, Rock Island & Pacific Railway Co., has shown that fatigue failure occurs in railroad axles and forgings where flow lines come to the surface.

[9] H. F. Moore and J. B. Kommers, "An Investigation of the Fatigue of Metals," *Bulletin No. 124*, University of Illinois (1921).

[10] W.N. Thomas, "The Effect of Scratches and Various Workshop Finishes upon the Fatigue Strength of Metals," *Engineering*, October 12 and 19, 1923; *Reports and Memoirs No. 860*, British Aeronautical Research Committee, Vol. 2, p. 542 (1923–1924); *Revue de Metallurgie*, Extraits, p. 210 (1924).

[11] R. Faulhaber, *Zeitschrift* des Vereines Deutscher Ingenieure, Band 78, No. 11.

[12] D. J. McAdam, Jr., and R. W. Clyne, "Influence of Chemically and Mechanically Formed Notches on Fatigue of Metals," *Journal of Research*, Nat. Bureau Standards, Vol. 13, October, 1934 (*Research Paper 725*).

[13] R. E. Peterson, "Fatigue Tests of Large Specimens," *Proceedings*, Am. Soc. Testing Mats., Vol. 29, Part II, p. 371 (1929).

[14] O. J. Horger, "Effect of Surface Rolling on the Fatigue Strength of Steel," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 57, p. 128 (1935).

From the varied discussion above, it is apparent that no definite basis for the scatter may be safely allocated at this time. Six axles were burnished or surface rolled in an attempt to increase the fatigue strength as indicated by the square points on the *S-N* curve of Fig. 7. None of these axles failed at bending stresses up to 37,500 psi. Rolling apparently offers a simple method of obliterating any detrimental influence of the factors of structural, forging, or processing conditions and has been shown to increase the fatigue strength without these factors being present,[14] but the number of tests made does not justify this general conclusion for the present.

$1\frac{1}{2}$-in. Specimens:

An endurance limit of 28,000 psi. established for this material is a value which may normally be expected for this diameter and these surface-finish conditions.[13, 14] The scatter in results is evident from Fig. 8 and particularly the delayed[15] type of fractures occurring at 50 and 100 million reversals. The nature of the smooth-turned surface finish in Fig. 5 (*b*) or the structural conditions present in an untreated material may be responsible. Micrographs of these test axles, not shown here, disclose a finer grain structure than for the full-size axles as a result of greater working and processing conditions. Incomplete tests on specimens having a rough turned surface, Fig. 5 (*c*), will show little if any decreased endurance limit over the smooth turned surface. Such differences as exist due to surface finish conditions may be masked by material conditions. Further tests are being made on both the rough turned specimens and some which will be super finished.

0.3-in. Specimens:

The endurance limit of 33,000 psi. established for this material is consistent with expectations and agrees with results by Moore[16] who found an endurance limit of 29,000 and 32,000 psi. for 0.3-in. specimens machined from full-size car axles of untreated steel. No discussion of size effect and its influence on the endurance limit for the various size specimens is given in this paper because of the large number of variables which preclude its evaluation.

SUMMARY OF CONCLUSIONS

Tests given here represent a progress report on the study of the fatigue strength of the body section of railroad car axles. While exceptionally few fatigue fractures occur in actual railroad service in the plain body sections of car axles, when pressed or clamped-on members are not applied, it is important to note from these tests that only 17,500 psi. is the endurance limit of the full-size axle as compared to 33,000 psi. for that of the usual 0.3-in. diameter specimens machined from the surface of the full-size axle. Various explanations are discussed as to the probable reasons for this large decrease in strength of the full-size axle but it is important that the designer take cognizance of this reduction when using an untreated and forged material in the machined condition discussed here.

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[15] Delayed type of fracture was discussed by H. J. French, "Fatigue and the Hardening of Steels," *Transactions*, Am. Soc. Steel Treating, October, 1933, but his results applied to structural conditions obtained by age hardening and quenched-and-tempered treatment of the material tested.

[16] H. F. Moore, S. W. Lyon and N. J. Alleman, "A Study of Fatigue Cracks in Car Axles," *Bulletin No. 197*, University of Illinois (1929).

Acknowledgment:

Appreciation is expressed to the Association of American Railroads for their permission to publish these results and also to T. V. Buckwalter, Vice President, of The Timken Roller Bearing Co. in his advisory capacity on these tests.

DISCUSSION

Mr. R. E. Peterson[1] (*presented in written form*).—For the purpose of discussion, it may be well to list the most likely causes of scatter and low endurance values for the tests reported:

1. Grain size
    (*a*) Variation
    (*b*) Coarseness
2. Forging effects
    (*a*) Flow lines
    (*b*) Residual stress
3. Surface
    (*a*) Turned finish
    (*b*) Corrosion pits
4. Testing temperature

In attempting to explain the large scatter and low values reported it should be recognized at the outset that a combination of several effects may be involved so that no one effect may be dismissed by establishing that it can produce only, for example, half of the observed effect. Starting with grain size effect it will be of interest to report results of fatigue tests made some time ago on material quite similar to that tested by Messrs. Horger and Neifert. The material was 0.45 per cent carbon steel in the "as rolled" condition. Different bars showed different degrees of coarseness. The data for polished specimens are shown in the accompanying Fig. 1. Material A was very coarse, similar to that shown in the authors' Fig. 10 (*b*); material B was fairly coarse, similar to Fig. 10 (*c*). It is interesting to note that the difference in coarseness did not produce a large difference in fatigue results; also that the 1 and 2-in. diameter specimens gave about the same endurance limits. It is of further interest that the endurance limit of the 0.3-in. diameter polished specimens taken from an axle as reported by Messrs. Horger and Neifert is in agreement with the corresponding data of the accompanying Fig. 1, while the endurance limit of the smooth turned 1.5-in. diameter specimens from special forgings is lower than the corresponding data. In the case of the seventeen 0.3-in. diameter specimens taken from center to outside of the axle it is to be noted that these do not show large scatter and in no case is a low value obtained. Referring to grain size effect, it does not seem likely that coarseness or variation of grain size contributes to any considerable degree

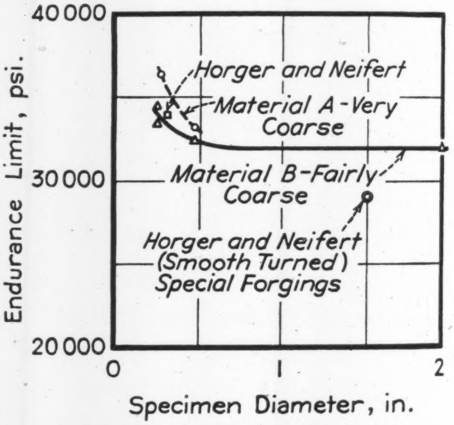

Fig. 1.—Fatigue Test Data Medium Carbon Steel (not Heat Treated) Polished Specimens Except in One Case as Noted.

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[1] Manager, Mechanics Division, Westinghouse Research Laboratories, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

in explaining the large scatter and low values obtained.

With regard to forging effects, flow lines or ghost lines look rather alarming after etching but apparently do not affect strength greatly. In tests made some time ago on medium-carbon steel (accompanying Fig. 2) longitudinal streaks had practically no effect and transverse streaks resulted in a 12 per cent decrease in strength. Unless the forging effect is a more subtle one than is apparent from the evidence at hand, it does not seem to be a probable major effect. Another possibility, is that of residual stress since no normalizing treatment was given. It is not possible to estimate accurately such stresses but their presence could explain a considerable portion of the scatter and the low values obtained.

Under surface effects, a turned but not polished finish would result in a somewhat lower fatigue limit but would not be expected to produce great scatter. Corrosion pits would also produce lower values but in addition would be expected to show considerable scatter.

Heating effects can be dismissed if the specimens were not sufficiently warm to be uncomfortable to the hand.

Summarizing, and keeping in mind that the net result may involve a combination of effects, it appears to the writer that the factors most likely to contribute major effects are corrosion pits and residual stress; with minor effects most likely due to grain size and turned finish. It is apparent from the foregoing that a great deal could be learned by running a series of tests of axles with the body portion polished which could be done without interfering with regular press fit tests.

The results presented by the authors are directly useful to railway equipment designers and represent a valuable addition to our technical knowledge. It is hoped, however, that for the benefit of others who have problems such as strength of large rotors, additional tests will be made by the authors with a view

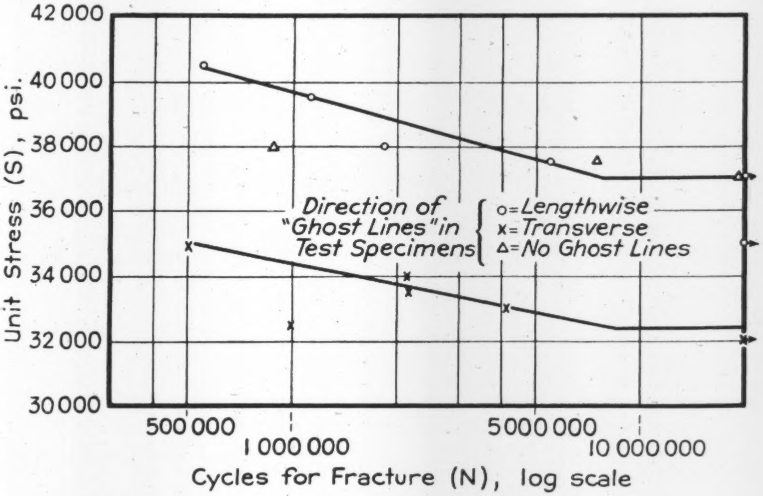

FIG. 2.—*S-N* Diagram Showing Directional Difference in Medium Carbon Steel Containing "Ghosts."

toward establishing definitely the major effects.

MR. H. E. SMITH.[2]—I can say that in the practical operation of axles with wheels mounted, it has been found that a great improvement has been obtained with a polished wheel fit as compared to the ordinary turning, and the rougher the turning the worse the operation.

MR. F. N. SPELLER.[3]—We all know that corrosion reduces fatigue endurance, and there is some indication that corrosion-fatigue data on small machine tests somewhat exaggerate the effect of corrosion. Therefore it will be useful to repeat some of these tests on full-size sections where machines are available. I do not mean to minimize the effect of corrosion fatigue, but it will be useful indeed when we have such tests on specimens that are more nearly full size.

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[2] Materials Engineer, White Plains, N. Y.

[3] Advisory Engineer, National Tube Co., Pittsburgh, Pa.

FINE FOCUS RADIOGRAPHY—GAMMA RAYS

By Gilbert E. Doan[1] and Milton B. Vordahl[1]

Synopsis

The present study attempts to determine how narrow an internal crack in a metal object can be revealed under the best possible radiographic conditions.

Using a bulb of radon so small that it approximates a point source of radiation, namely, $\frac{1}{16}$ in. in diameter, it was possible to detect cracks 0.001 in. wide in blocks of steel 1 in. thick, and cracks 0.002, 0.003, and 0.005 in. wide in 2-in., 3-in., and 4-in. blocks, respectively. Each crack was $\frac{1}{4}$ in. deep. Cracks of this fineness would probably escape detection with sources of the usual dimensions. Even narrower cracks than these can be detected if they are deeper than $\frac{1}{4}$ in., or lie in thinner metal sections.

The distance from source to specimen was brought down as low as 1 in. in some cases without sacrificing the detectability of these cracks, and with but slight loss in shadow sharpness. The necessary exposure time is thus greatly shortened.

A recent investigation (**1**)[2] of the geometry of radiography pointed out the value of using a source of the smallest possible diameter. This investigation also prompted the question: "What is the narrowest crack that can be detected by gamma rays?"

Using a source 0.138 in. in diameter, the authors found some indication that flaws $\frac{1}{64}$ in. in width would not register even with a source-to-specimen distance of 26 in. Since many dangerous flaws, especially cracks, could exist in a structural member 2 in. thick and go undetected if $\frac{1}{64}$ in. were the limit of sensitivity, it seemed desirable to investigate further the limits of width sensitivity. Furthermore, the development of a technique that would extend the limits of sensitivity beyond those generally recognized would apparently be of great value. It was for these and related purposes that the present work was undertaken.

The only concern with regard to *depth* of flaw was that in all cases it should fall well within the reported limits of depth sensitivity. Norton and Ziegler (**2**) report a sensitivity of 1.3 per cent in the range from $2\frac{1}{2}$ to 6 in. of steel. Since $\frac{1}{4}$ in. depth or more was used in all cases in the present work, the least percentage depth was 6.25, this minimum being in the case of $\frac{1}{4}$ in. deep flaws in 4 in. of steel.

Experimental Work

A bulb of radon with an initial strength of 45.6 millicuries was used as a source of gamma rays. The bulb had an inside diameter of about $\frac{1}{16}$ in. and was contained in a small brass capsule.

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[1] Professor of Metallurgy, and Gotshall Scholar in Metallurgy, respectively, Lehigh University, Bethlehem, Pa.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 747.

During most of the work the bulb was removed from the capsule and held in a thin-walled glass funnel. Later the bulb was replaced in the capsule for the purpose of determining what, if any, effect the capsule might have on the sharpness of shadows.

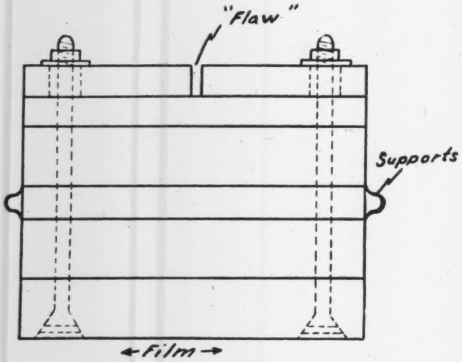

FIG. 1.—Diagram of Specimen Showing Slit.

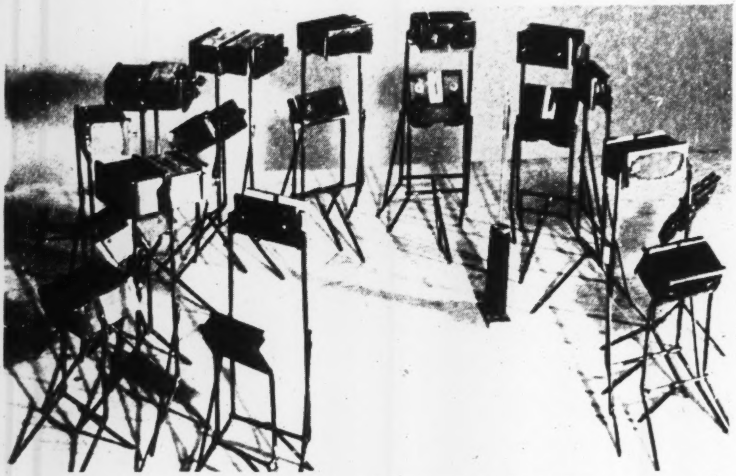

FIG. 2.—Arrangement of Specimens on Supports.

The specimens to be radiographed were built up from blocks and plates of steel of various thicknesses bolted together as shown in Fig. 1. The edges of the plates forming the slits or artificial cracks were finely ground so that the slits would be of precise dimensions. The bolt holes were drilled large enough to allow movement of the plates so that the slit width could be varied at will. The width of the slit was set by clamping the ground edges against a feeler-gage blade of the desired thickness and then tightening the bolts. Wire supports were designed so that a large number of specimens could be arranged about the source and so that placement, alignment, and removal of the specimens were easy. Figure 2 shows the system used.

The use of artificial "cracks" may be open to criticism. But the alternative is to use natural cracks which vary in width, thickness, and angle so uncontrollably that one crack can never be compared with any other, nor given a definite rating. The present results can be reproduced at will and checked by any interested person. Artificial cracks provide a dependable method for comparison of results and thus aid in the appraisal and refinement of the process.

The films were held in paper packs with three lead screens. A $\frac{1}{8}$-in. lead plate backing was employed to furnish rigidity and to eliminate back-scattering.

The packs were fastened to the backs of the specimens by means of rubber bands. Eastman duplitized X-ray film was used throughout the work, with standard procedure for development.

TABLE I.

Test	Film	Specimen Thickness, in.	Source-to-Specimen, in.	Width of Slit, thousandths of an inch	Visibility Index[a]
No. 1	No. 21	¼	12	5	10
No. 2	No. 22	¼	12	2	6
No. 3	No. 23	¼	12	0+	2
No. 4	No. 3	½	5.5	5	6
No. 5	No. 4	½	13	2	4
No. 6	No. 28	½	5.5	2	..[e]
No. 7	No. 36	½	13	1.5	4
No. 8	No. 41	½	3	10	8
No. 9	No. 45	½	3	1.5	2
No. 10	No. 54	½	10	1.5	3
No. 11	No. 67	½	3	1.5	3
No. 12	No. 69	½	18	1.5	4
No. 13	No. 74	½	3	1.5	5
No. 14	No. 75	½	18	1.5	5
No. 15	No. 88	½	3[b]	1.5	3
No. 16	No. 93	½	3	0+	3
No. 17	No. 94	½	3	1	4
No. 18	No. 96	½	3[b]	1	3
No. 19	No. 98	½	1[b]	1	3
No 20	No. 100	½	1[b]	0+	2
No. 21	No. 115	½	5.5	5	6
No. 22	No. 116	½	3	10	8
No. 23	No. 5	1	3	25	12
No. 24	No. 6	1	4.3	15	10
No. 25	No. 7	1	6	10	8
No. 26	No. 8	1	11	5	6
No. 27	No. 25	1	11	2	..[e]
No. 28	No. 31	1	5	5	5
No. 29	No. 34	1	5	5	7
No. 30	No. 37	1	5.5	1.5	..[e]
No. 31	No. 42	1	3	10	8
No. 32	No. 46	1	3	10	7
No. 33	No. 55	1	10	1.5	..[e]
No. 34	No. 65	1	6	5	6
No. 35	No. 68	1	3	1.5	3
No. 36	No. 70	1	18	1.5	4
No. 37	No. 71	1	3	1.5	4
No. 38	No. 72	1	10	1.5	4
No. 39	No. 73	1	18	1.5	4
No. 40	No. 86	1 (m=⅛")[c]	3	1.5	4
No. 41	No. 87	1 (m=¼")[c]	3	1.5	2
No. 42	No. 89	1	3[b]	1.5	4
No. 43	No. 90	1	3[b]	1.5	4
No. 44	No. 91	1	3	0 to 5[d]	4
No. 45	No. 92	1	3	1	2
No. 46	No. 95	1	3[b]	0 to 5[d]	4
No. 47	No. 97	1	1[b]	0 to 5[d]	4
No. 48	No. 101	1	1[b]	5	5
No. 49	No. 111	1	3	5	5
No. 50	No. 112	1	5	0 to 5[d]	5
No. 51	No. 113	1	2	45 (holes)	..
No. 52	No. 114	1	4	45 (holes)	..
No. 53	No. 117	1	5	5	6
No. 54	No. 118	1	3	10	8
No. 55	No. 9	2	5.3	30	10
No. 56	No. 10	2	7	20	8
No. 57	No. 11	2	8.6	15	7
No. 58	No. 12	2	14.5	8	7
No. 59	No. 27	2	14.5	3	3
No. 60	No. 29	2	5.3	10	7
No. 61	No. 33	2	5.3	3	4
No. 62	No. 38	2	5.3	1.5	0
No. 63	No. 39	2	18	1.5	0
No. 64	No. 40	2	3	2	3
No. 65	No. 43	2	3	10	6
No. 66	No. 47	2	3	10	7
No. 67	No. 49	2	14.5	3 (interior)	4
No. 68	No. 56	2	10	1.5	0
No. 69	No. 60	2	8 (m=⅔")[c]	0 to 10[d]	5
No. 70	No. 61	2	8 (m=1⅓")[c]	0 to 10[d]	5
No. 71	No. 62	2	8 (m=⅓")[c]	0 to 10[d]	5
No. 72	No. 63	2	8	0 to 10[d]	6
No. 73	No. 66	2	10	1.5 (½" deep)	5
No. 74	No. 85	2	3	1.5	0
No. 75	No. 102	2	1	2	0
No. 76	No. 109	2	3	0 to 10[d]	5
No. 77	No. 110	2	1.5	0 to 10[d]	3
No. 78	No. 119	2	3	10	8
No. 79	No. 120	2	3	45 (holes)	6
No. 80	No. 14	3	8	30	9
No. 81	No. 15	3	10.5	20	7
No. 82	No. 16	3	18	10	6
No. 83	No. 30	3	8	2.	0
No. 84	No. 32	3	18	5	4
No. 85	No. 35	3	8	5	4
No. 86	No. 44	3	3	10	6
No. 87	No. 48	3	8	3	2
No. 88	No. 50	3	8	5 (interior)	4
No. 89	No. 17	4	8	50	10
No. 90	No. 18	4	9	40	10
No. 91	No. 19	4	12	25	8
No. 92	No. 20	4	16	15	6
No. 93	No. 26	4	8	3	0
No. 94	No. 26a	4	16	3	0
No. 95	No. 51	4	8	5	4
No. 96	No. 52	4	3	10	6

[a] Visibility increases with index number. See text for explanation. "0" indicates no visible shadow.
[b] Source replaced in brass capsule.
[c] *m* is the perpendicular distance from the source to the axial plane of the slot.
[d] V-shaped slot.
[e] Accident in developing.

Exposure times were derived from the tables and charts established by Barrett, Gezelius, and Mehl (3) using a 50 per cent overexposure.

The specimens were arranged to give what promised to be the maximum sensitivity; that is, the axial plane of the slit was pointed precisely at the incident rays. But the slit was located in the most disadvantageous position, namely at the surface of the specimen facing the radiation (surface farthest from film). A few specimens were arranged with the axial plane of the slit at an angle to the rays, and in some cases the slit was placed within the specimen.

RESULTS AND DISCUSSION

Throughout the paper, "sharpness" is taken to mean the abruptness with which the shadow grades from maximum to 0 density difference.

In order to facilitate comparison of results for those who cannot view the films, a "visibility index" was devised and included in Table I. The index is based on the maximum distance at which the shadow image on the film can be clearly seen, higher indices indicating shadows visible at greater distances. Index values of 2 indicate that optimum or near optimum distance was necessary to see the shadow image clearly. In using the index, one must keep in mind that a high visibility index does not necessarily mean great *sharpness*, because a broad, diffuse band appears more distinct when viewed from a distance. Typical prints of radiographs with visibility indices noted are included for reference, see Fig. 3. Since detail is lost twice in these reproductions—once in photographic printing and once in half-tone reproduction—it is not surprising if the indices based on the films do not agree with these reproductions.

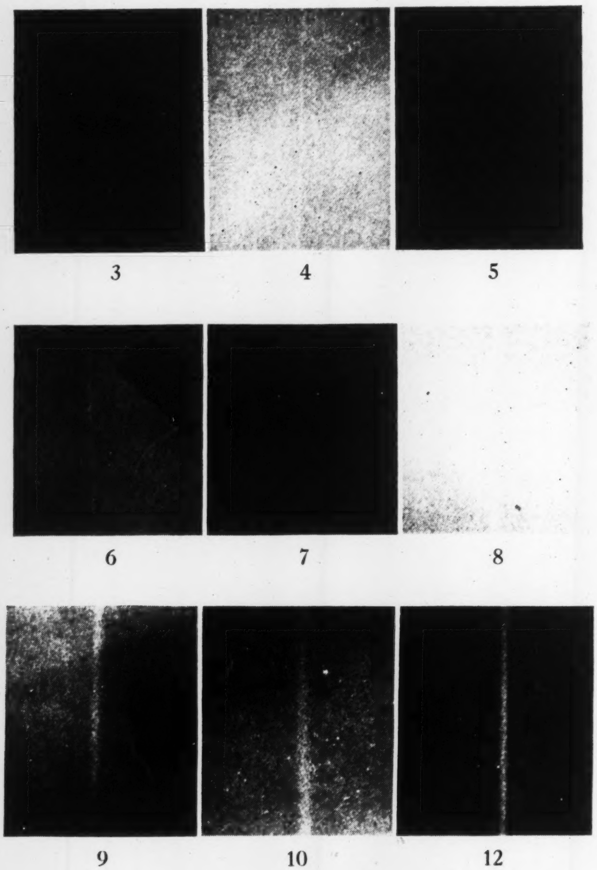

FIG. 3.—Typical Slit Images and Visibility Indices.

½- and 1-in. Thick Specimens, ¼-in. Deep Slits:

With slits 0.001 in. wide in both ½ and 1-in. specimens and with a source-to-specimen distance of 3 in., very sharp and clear registry was obtained, the shadow appearing as an exceedingly fine line on the film (tests Nos. 17, 18, 19, and 45). With the ground edges of the ¼-in. plates pressed as tightly together as possible ("compressed slit"), visible registry was still obtained from ½-in. specimens, but so faintly that it is doubtful whether it would have been detected on the film if it were anything but a straight line (test No. 16).

Increasing the distance beyond 3 in. (using 0.0015-in. slits) resulted in very little visible increase in sharpness (tests Nos. 7, 9, 10, 11, 12, 13, 14, and 15).

With slits 0.0015 in. wide and turned at an angle to the incident rays, the shadows became very diffuse but did not disappear (tests Nos. 40 and 41). This indicates that registry of even such narrow slits as 0.0015 in. is not entirely dependent upon perfect alignment.

Radon Bulb in Capsule.—Using identical specimens and similar arrangements, exposures were made both with the bulb in the capsule and out. There was little distinguishable difference in the sharpness of the shadows obtained (tests Nos. 15, 18, 19, 20, 42, 43, 46, 47, and 48). (Note that there is some slight indication that with ½-in. specimens, enclosing the bulb in the capsule decreased the visibility. Compare test No. 15 with No. 13, and No. 18 with No. 17.)

Shortening the source-to-specimen distance below the 3 in. reported in the paragraph above gave clear registry of compressed slits in ½-in. specimens at 1 in. distance (test No. 20). The 1-in. specimens at 1 in. distance showed clear registry of a slit width of 0.001 in. (test No. 47).

2-in. Thick Specimens, ¼-in. Deep Slits:

A slit 0.002 in. wide with a source-to-specimen distance of only 3 in. gave fairly distinct registry (test No. 64). Reducing the distance to 1 in., however, prevented registry (test No. 75). Using a slit 0.0015 in. wide, no registry was obtained at any source-to-specimen distances tried (tests Nos. 62, 63, 68, and 74). However, when the depth of the flaw was increased to ½ in., sharp, clear registry was obtained (test No. 73).

Using V-shaped openings with the top of the V 0.010 in. wide and the bottom tightly closed and using source-to-specimen distances of 1½, 3, and 8 in., shadows were obtained which in each case extended to a point corresponding to a slit width of about 0.002 in., the only effect of the increasing source-to-specimen distance being to increase the sharpness (tests Nos. 72, 76, and 77). With a similar V-shaped slit but turned at an angle to the incident rays, a broadening similar to that mentioned before was noted, with only a slight decrease in visibility (tests Nos. 69, 70, and 71).

There was little increase in sharpness when the source-to-specimen distances were increased beyond relatively small values (tests Nos. 59, 61, 72, 76, and 77). This observation, along with the above-mentioned fact that a 0.002-in. slit gave visible registry at a 3-in. source-to-specimen distance (test No. 64), and that a 0.0015-in. slit would not show at any distance of source-to-specimen, seems to indicate that there is no advantage in detectability and only slight advantage in sharpness in increasing the source-to-specimen distances beyond certain low limits. (This, however, cannot be as definitely stated for 3- and 4-in. specimens, for an insufficient number were radiographed to give conclusive evidence.)

3-in. Specimens and $\frac{1}{4}$-in. Deep Slits:

Slits 0.003 in. wide showed only very faintly with a source-to-specimen distance of 8 in. (test No. 87). Slits 0.005 in. wide under the same conditions gave clear and fairly sharp shadows (test No. 85). Increasing the source-to-specimen distance to 18 in. caused little increase in sharpness (test No. 84). With slits 0.010 in. wide, a source-to-specimen distance of 18 in. gave a very material increase in shadow sharpness (test No. 82) over that obtained with a 3-in. source-to-specimen distance (test No. 86), but no increase in visibility. (Shadow widths were roughly $\frac{1}{64}$ in. and $\frac{1}{16}$ in., respectively.) Locating the slits in the interiors of the blocks caused little or no difference in shadow sharpness (compare tests Nos. 85 and 88).

4-in. Specimens and $\frac{1}{4}$-in. Deep Slits:

Slits 0.003 in. wide produced no shadow at any source-to-specimen distance tried (tests Nos. 93 and 94). Unmistakable registry was obtained with slits 0.005 in. wide and a source-to-specimen distance of 8 in. (test No. 95). Comparisons of shadows obtained with source-to-specimen distances of 3, 8, 12, and 16 in. show greatly increased sharpness from 3 to 8 in., but relatively little increase beyond 8 in. (tests Nos. 96, 95, 91, and 92). These comparisons, however, are not quantitative because the slits were of varying widths and comparisons become largely a matter of opinion.

Non-Linear Flaws:

In order to investigate the shadow sharpness obtainable with *non-linear* flaws, patterns of holes 0.045 in. in diameter were drilled in a $\frac{1}{4}$-in. plate and the plate placed on the source side of blocks $\frac{3}{4}$ in. and $1\frac{3}{4}$ in. thick and at varying source-to-specimen distances. With the $\frac{3}{4}$-in. blocks, sharp shadows of the pattern were obtained with source-to-specimen distances of 2 in. (test No. 51) and with the $1\frac{3}{4}$-in. blocks a source-to-specimen distance of 3 in. gave clear and fairly sharp shadows (test No. 79). Facilities were not available for drilling smaller holes.

A number of crack and hole systems of various shapes, and several welds were radiographed under varying conditions in order to check further the indications obtained.

SUMMARY

Using a bulb of radon $\frac{1}{16}$ in. in diameter, it was possible to detect cracks 0.001 in. wide in blocks of steel 1 in. thick, and cracks 0.002, 0.003, and 0.005 in. wide in 2-, 3-, and 4-in. blocks, respectively. Each crack was $\frac{1}{4}$ in. deep. Cracks of this fineness would probably escape detection with sources of the usual dimensions. Even narrower cracks than these can be detected if they are deeper than $\frac{1}{4}$ in., or lie in thinner metal sections.

In "fine-focus radiography" that is with a source of very small diameter, very short source-to-specimen distances can be used without loss of detectability and with but little loss in sharpness.

Considering necessary exposure time, desired shadow sharpness, and flaw detectability, the authors make the following recommendations for a $\frac{1}{16}$-in. source:

Metal Thickness, in.	Source-to-Specimen Distance, in.	Exposure Time (50-millicurie source)[a]
½	2	4.5 min.
1	3	18 min.
2	4	90 min.
3	6	7.5 hr.
4	8	34 hr.

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[a] These times can be reduced 30 per cent by using a special developing technique (3).

Although the authors obtained near maximum sensitivity using lower values, the above are given as minima to be used with certainty of detecting everything detectable.

Acknowledgment:

The authors are indebted for the radon used in these experiments to the Radium Chemical Co. of New York City, and for the fellowship under which the investigation was carried out to endowment provided by Mr. William G. Gotshall.

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(2) J. T. Norton and A. Ziegler, "Sensitivity of the Gamma-Ray Method," *Transactions*, Am. Soc. Steel Treating, Vol. 22 (1933).

(3) C. S. Barrett, R. A. Gezelius and R. F. Mehl, "The Technique of Radiography by Gamma Rays," *Metals and Alloys*, Vol. 1 (1930).

DISCUSSION

Mr. Alexander Gobus.[1]—The work reported here by Messrs. Doan and Vordahl is very interesting and worth while, particularly in view of one specification that I know of, issued by the Navy which limits the use of radium in radiography of cylinders at not less than 12 in. from source to film, despite the fact that the Navy standards show some fourteen radiographs which were taken at lesser distances, some of these as low as 4½ in.

We have made some single films, one of them 52 in. long, taken with radium in the center of a 14-in. pipe and a 12-in. pipe with about 1-in. walls where the radium used was 100 mg. I think those who examine these films will be satisfied with the showing of the penetrometer as well as several cracks and defects. In view of all this the Radium Chemical Co. should make an effort to provide the industry with much smaller focal spots than are now available, and incidentally change the duralumin container from its oval egg shaped affair, which was originally designed to be held in a funnel, to a round ball that can be held in almost anything encountered in the field.

I might mention that in field work on pipe lines, we have developed the use of film that is cut to the desired size in the field; in other words, we buy film 5 in. wide by 50 ft. long and cut that to 18, 20, 40, or 50 in. or whatever the diameter of the pipe requires, so that we can use a single strip of film instead of a lot of small pieces. The latter may not always overlap enough and even if they do are a nuisance in interpretation.

Mr. Gilbert E. Doan[2] (*author's closure by letter*).—In reply to Mr. Gobus, I believe the time is not far distant when radium will be available in very small spheres. The X-ray people likewise are, I understand, attempting to develop tubes with much smaller focal spots in order to gain the advantages pointed out by these experiments.

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[1] Metallographist, Lucius Pitkin, Inc., New York City.

[2] Professor of Metallurgy, Lehigh University, Bethlehem, Pa.

CORRELATION OF SOME MECHANICAL TESTS OF ALUMINUM ALLOYS WITH X-RAY TESTS

By Tom A. Triplett[1] and W. Lavern Howland[2]

Synopsis

Due to the increasing use of radiographic testing, a study was made in order to evaluate certain X-ray observations with mechanical tests. Both forged and cast material were studied in order to find the difference in mechanical properties with what was called radiographic quality. Arbitrary scales of quality were set up and mechanical tests were made after classifying the quality of a particular specimen. Curves were then plotted and the results show that correlation is obtained between X-ray tests and mechanical tests for both a forged and a cast material.

Probably the two most necessary developments in materials testing in the near future are: first, a rational correlation between special nondestructive tests and regular mechanical tests which would enable the engineer to evaluate more exactly the results of the former; and second, further development of nondestructive tests. At the present time, the primary nondestructive tests are magnetic analysis, magnaflux, electrical, X-ray diffraction, radiography, and visual examination of the outer surfaces. The present paper will consider only radiography, since it is the most important nondestructive test, for the examination of airplane parts. Magnetic analysis is limited in its application to a few aircraft parts only, and X-ray diffraction methods are in need of much further development before they can be classed as widely useful nondestructive tests.

Since two papers have recently been presented on radiographic technique and data,[3] the present paper is limited to a meager discussion of this subject. Roughly, a radiograph is the portrayal of density variations in a material by means of differential absorption of X-rays. For example, the film is darkened to a greater degree in those regions where the specimen is less dense as a result of blowholes, shrinkage cavities, interdendritic porosity, and other conditions. Needless to say, proper equipment and films and highly skilled technicians are required to obtain satisfactory results by radiographic methods.

Tests on Forged Billets of 14S-T:

The authors have made various mechanical tests on 14S-T similar to those described by Mechling and Jack in their paper, "Some Mechanical Tests on

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[1] X-ray Metallurgist, and President, Triplett & Barton, Inc., Burbank, Calif.

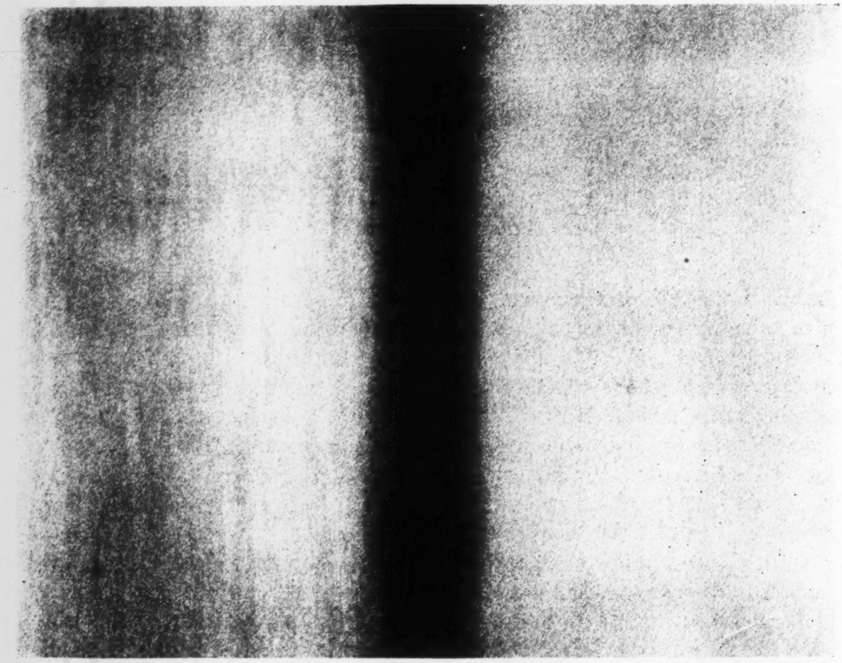
[2] Assistant Director of Research, Guggenheim Aeronautics Laboratory, California Institute of Technology, Pasadena, Calif.

[3] T. A. Triplett, "X-ray Inspection of Materials," *Arrow Digest*, Vol. 33, No. 1, July, 1938.

T. A. Triplett, "X-rays and Gamma Rays, Their Industrial Applications," *Journal*, Soc. Automotive Engrs., Vol. 40, No. 3, March, 1937.

Aluminum Alloys 14S-T and 24S-T,"[4] with the additional variables that the material was from 32 different billets of varying thickness ($\frac{1}{2}$ to 5 in.) and was obtained partly from Douglas, Lockheed and Consolidated aircraft companies, who purchased the material from a large reliable source over an 18-month period. Tests were made on both hand-forged and die-forged material and the composition was substantially as follows:

Copper, per cent	4.45
Iron, per cent	0.41
Silicon, per cent	0.80
Magnesium, per cent	0.38
Manganese, per cent	0.76
Aluminum	balance



(*a*) Showing structure with waviness. (*b*) Showing structure without waviness (good quality).

FIG. 1.—Radiograph of 14S-T Forged Bar.

The above analysis was taken from certified reports given by the source of supply. This investigation was prompted by the fact that different billets—and even different parts of the same billet—were characterized by different types of radiographs. Figure 1 illustrates the difference which can be observed in radiographs of these wrought alloys. The cause of the wavy appearance in Fig. 1 (*a*) is not definitely known at the present time. It was first believed that this waviness might be due to the segregation of undissolved constituents. However, photomicrographs of the material failed to substantiate this interpretation. It was then believed to be the effect of crystal orientation, but microstudies did not support this assumption. Recent investigation tends to show that the waviness may be due to a diffraction of the X-rays. In spite of the fact that the cause of this wavy appearance is not definitely known, it has been definitely established that the material which produced a wavy appearance in the radiograph gave a different diffraction pattern than that which did not. The intensity and pattern of the spots for the material which produced waviness was much greater and larger than that produced by the other material under similar conditions. This result suggests the fact that the difference in radiographic appearance may be due to grain size. In any event, it has been assumed for the present discussion that it is an indication of inferior material. An arbitrary scale of quality has been set up based on the assumption that the greater the contrast and waviness, the poorer the quality. Figure 2 shows radiographs made from specimens having quality values of No. 3 and No. 1. A No. 2 quality would lie between these two in contrast and amount of waviness, but has been omitted due to the difficulty of reproducing radiographs.

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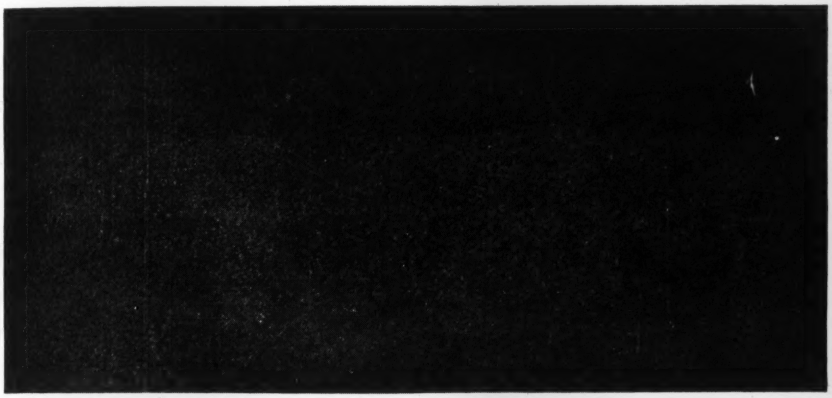
[4] See p. 769.

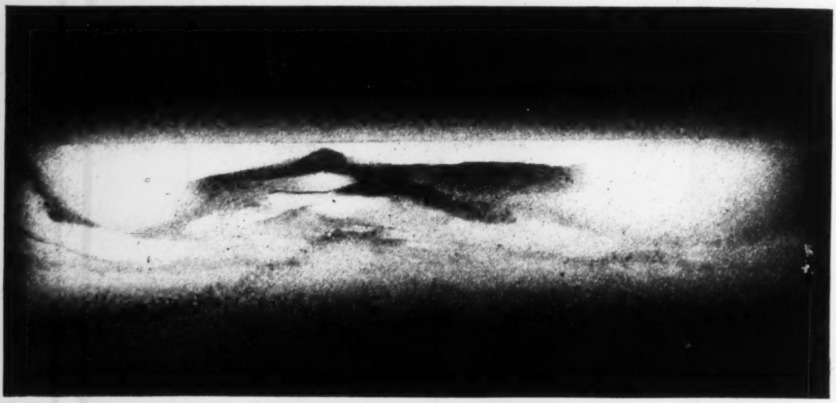


(*a*) Good structure (arbitrary scale quality No. 3).

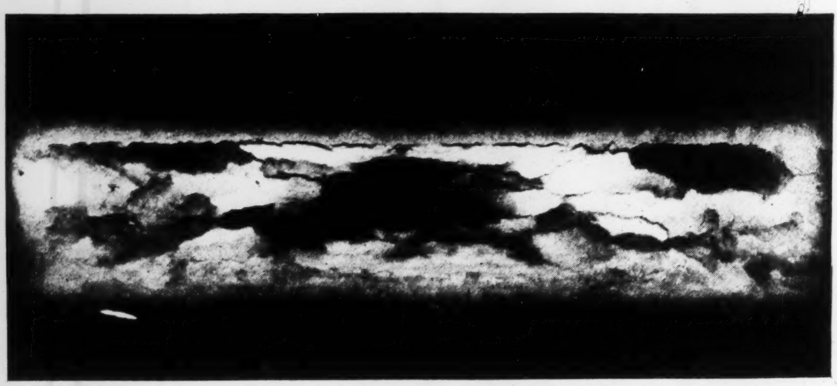
(*b*) Poor structure (arbitrary scale quality No. 1).

FIG. 2.—Radiographs of 14S-T Forged Bars.

The condition which produces the wavy appearance in Fig. 1 (*a*) affects the physical properties of the material. For example, the fracture of material such as that shown in Fig. 1 (*a*) has a fibrous structure as shown in Fig. 4; whereas, the fracture of good material, such as shown in Fig. 1 (*b*), has a homogeneous, velvety appearance such as that shown in Fig. 5 (*a*). Figure 5 (*b*) shows that of the intermediate structure. The relation between radiographic quality and type of fracture is shown in Fig. 3. These radiographs were made from specimen having the same shape as those illustrated in Fig. 4 with the X-ray beam normal to the plane of the fracture. Figure 3 (*b*) shows that a radiographic quality No. 1 is associated with a fibrous fracture. Figure 3 (*a*) shows that radiographic quality No. 2 is associated with a less fibrous fracture.



(*a*) Fair structure (arbitrary scale quality No. 2).



(*b*) Poor structure (arbitrary scale quality No. 1).

FIG. 3.—Radiographs of Fractured 14S-T Bars.

The results of mechanical tests on many hand-forged billets of 14S-T (some "good" with radiographic rating No. 3; some "fair" with radiographic rating No. 2; and some "bad" with radiographic rating No. 1) are plotted in Fig. 6. The 24S-T shown had a variation in grain size which was found by radiographic inspection. Each value is the average of 5 or more tests. The

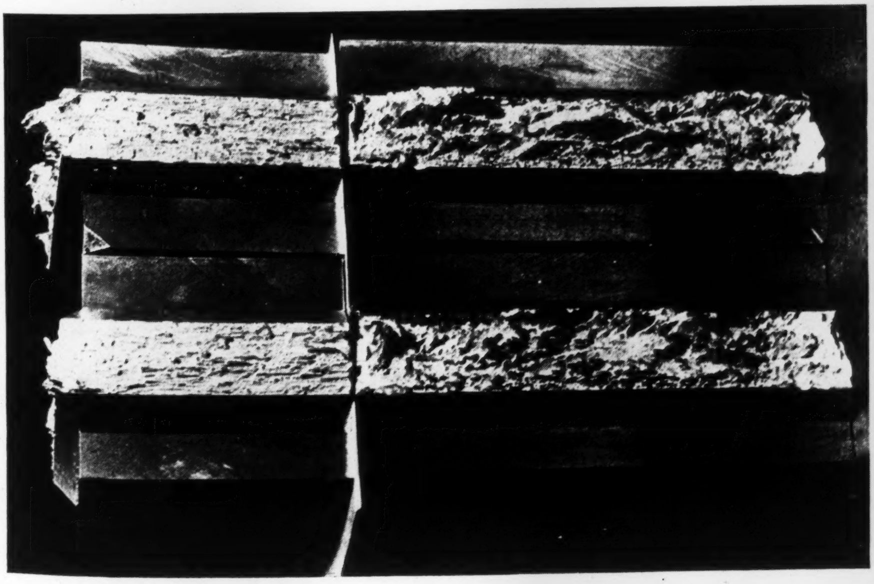
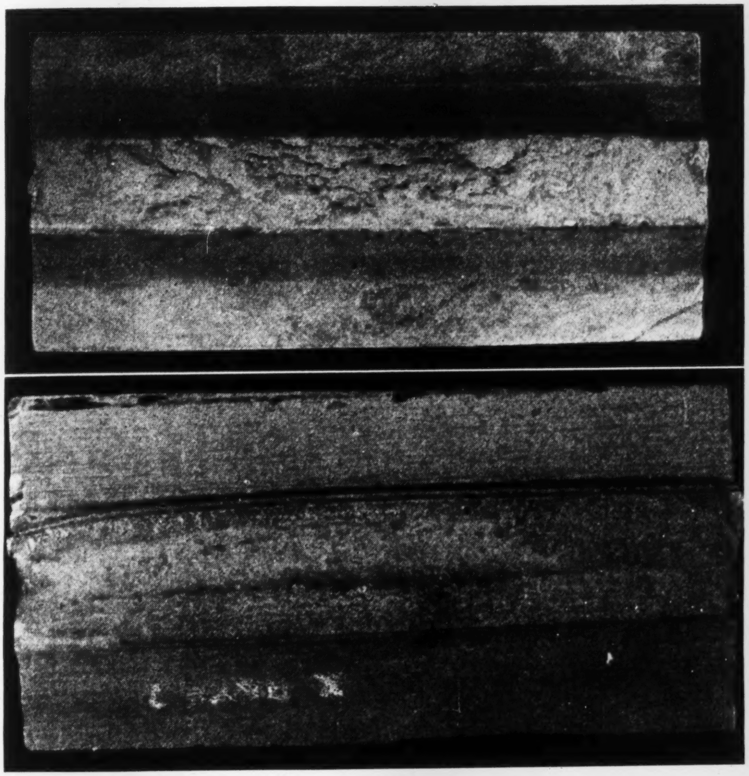


FIG. 4.—Photograph of Fracture Shown in Fig. 3 (*b*).
Note fibrous structure, over-all height 6 in.



(*a*) Good structure (note velvety structure). (*b*) Intermediate radiographic structure.

FIG. 5.—Fracture of 14S-T Bar.

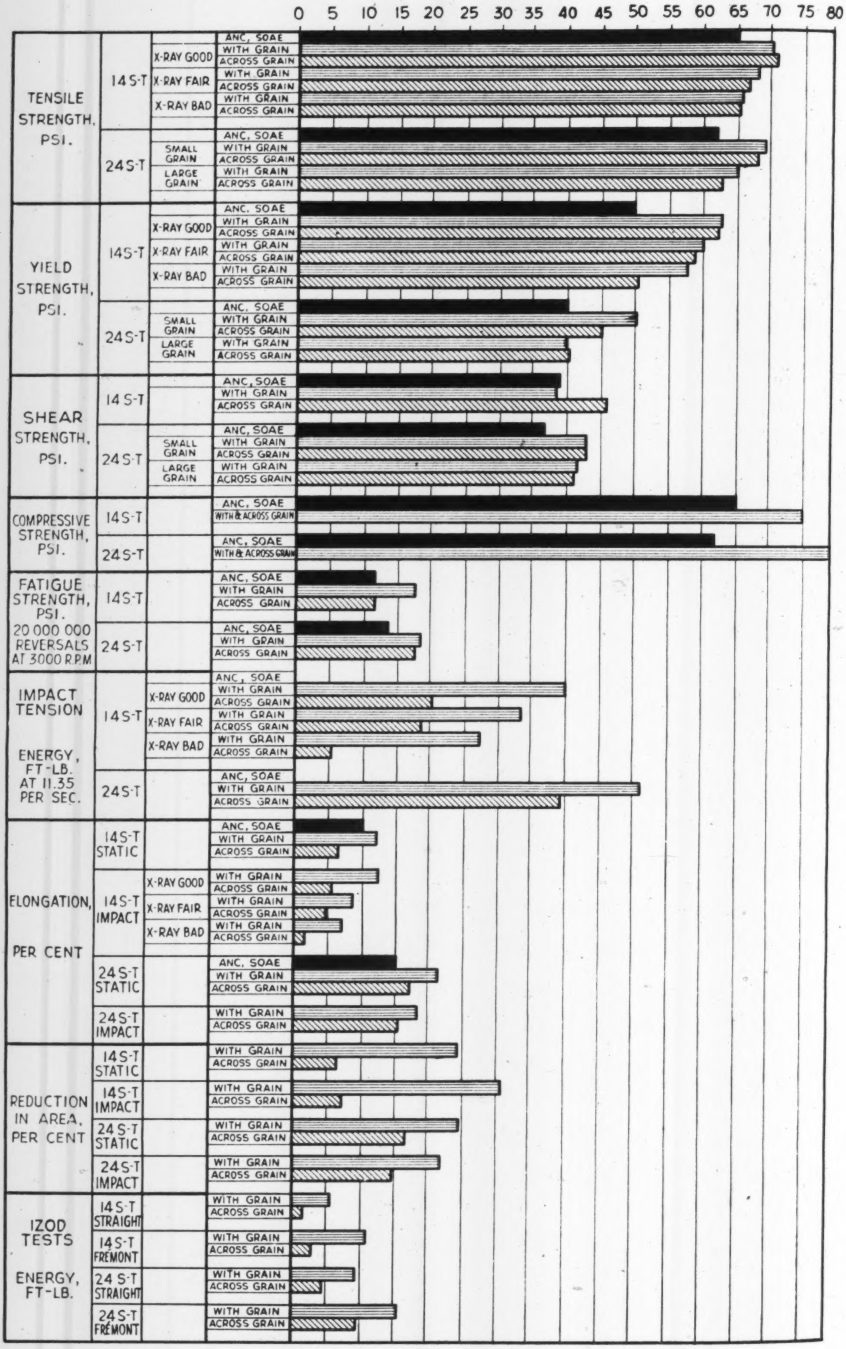


FIG. 6.—Comparison of the Physical Properties of Aluminum Alloys 14S-T and 24S-T. ANC, SOAE = Army, Navy, Commerce Standards of Aircraft Elements.

dimensions of the pieces have been indicated previously and the descriptions of the tests are given in the paper by Mechling and Jack,[4] which gives results on similar material but of more or less uniform quality.

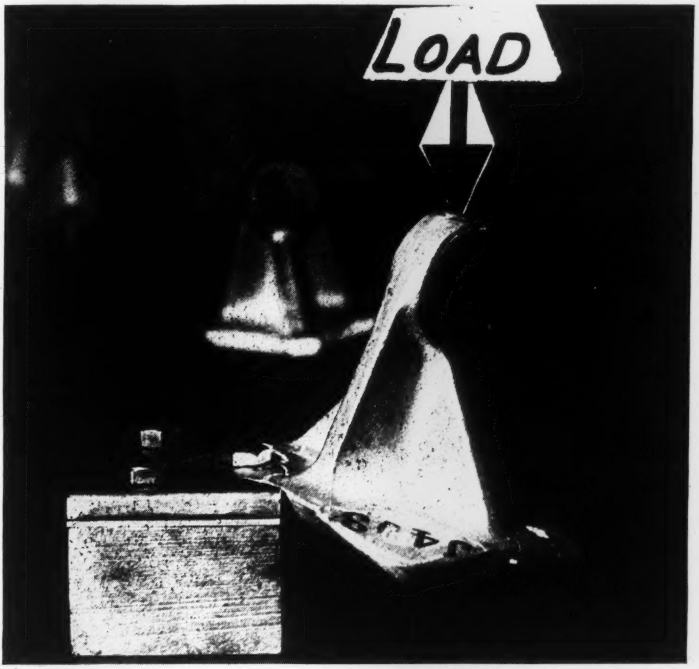


Fig. 7.—Methods of Testing Corners of Castings Under Bending and Shear.

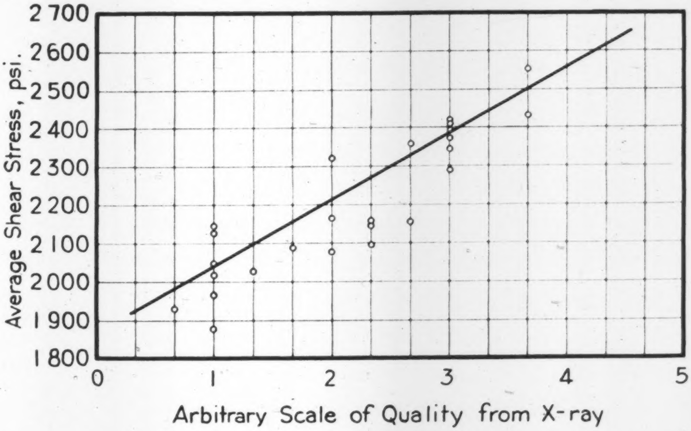
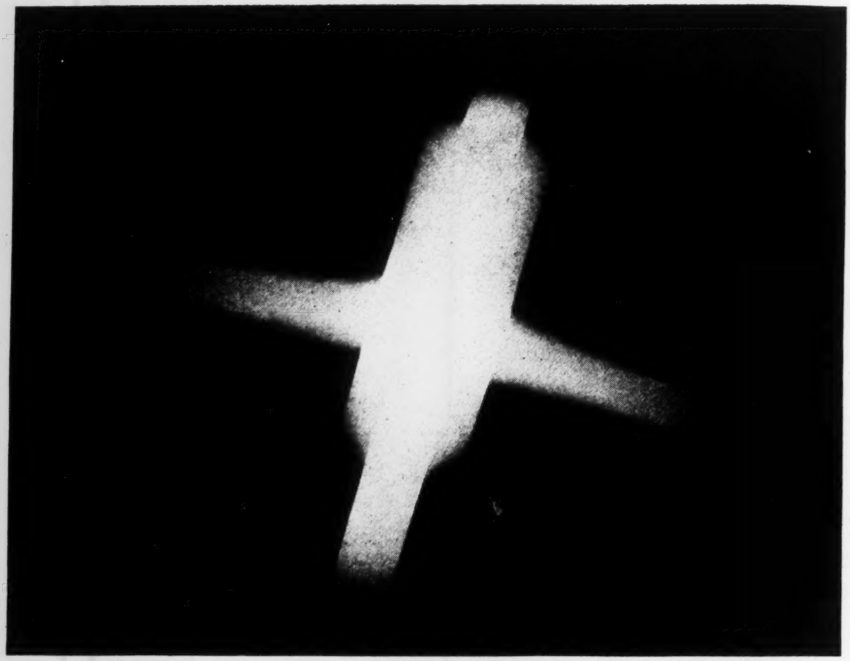


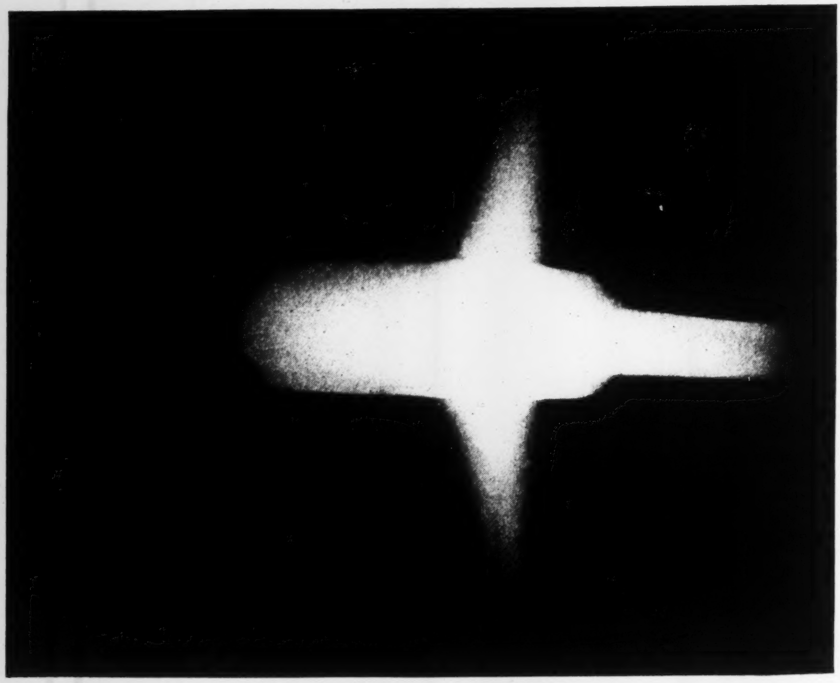
Fig. 8.—Correlation Between Static Tests of Bracket Castings and X-ray Tests.

Tests on Wrought Billets of 14S-T:

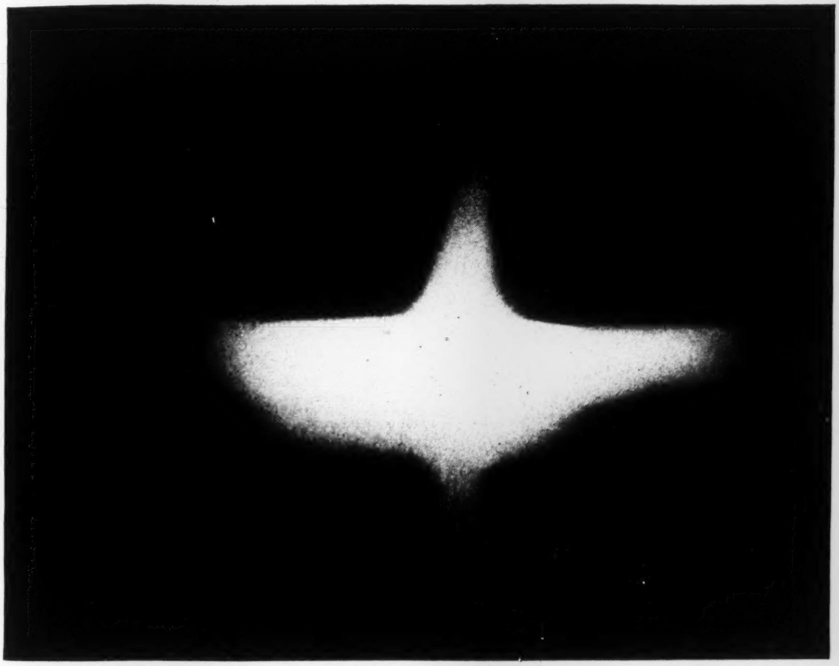
The results shown in Fig. 6 clearly indicate a correlation of radiographic quality with the results of mechanical tests. It is important to notice that there is no marked difference in static



(*a*) Fair base.



(*b*) Bad base (showing shrink porosity).



(*c*) Bad blow holes in base.

FIG. 9.—Radiographs of Bracket Castings.

properties of materials rated as "good" and "bad" by radiographic examination. However, the energy absorption, reduction of area, and percentage elongation in dynamic tests vary markedly in radiographic quality. For example, the tensile strength of 14S-T varied only 7 per cent and the yield point only 18 per cent between material judged "good" and "bad" from radiographic examination, but the energy absorbed in tension impact varied by 50 per cent when tested with the grain and by 75 to 90 per cent when tested across the grain. The static elongation values for good and bad material, which are not given in Fig. 6, varied by about 30 to 40 per cent. This is the only static property which approaches the amount of variation found in the dynamic properties.

This is a very interesting result, for it indicated that X-ray testing is sensitive to certain variations in the conditions or properties of materials which are not easily discovered or noticed in ordinary static tension testing. The reason that static tension testing is not sensitive to some of the variations in materials, which are indicated by radiographic inspection, is that such a test is insensitive to such things as small holes or inclusions well distributed. As a proof of this, K. Matthaes[5] found that, "under tensile stress, steel of round or solid sections always discloses an increase in strength (on the net area), especially if the influence of the notch or hole is confined to the outer zone of the piece; light alloys incur no loss of strength either." The above result means that if a material, for example, has porosity or a blowhole which reduces the net cross-sectional area by 10 per cent, then the static strength (load carried) will not decrease at all if the ultimate stress on the net area increases by 10 per cent. It might be mentioned at this point that it is very easy for X-ray examination to show up a decrease in cross-sectional area of 10 per cent of the thickness, and even as small a decrease

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[5] K. Matthaes, "The Influence of Notches Under Static Static Stress," *Technical Memorandum No. 862*, Nat. Advisory Committee for Aeronautics (1938).

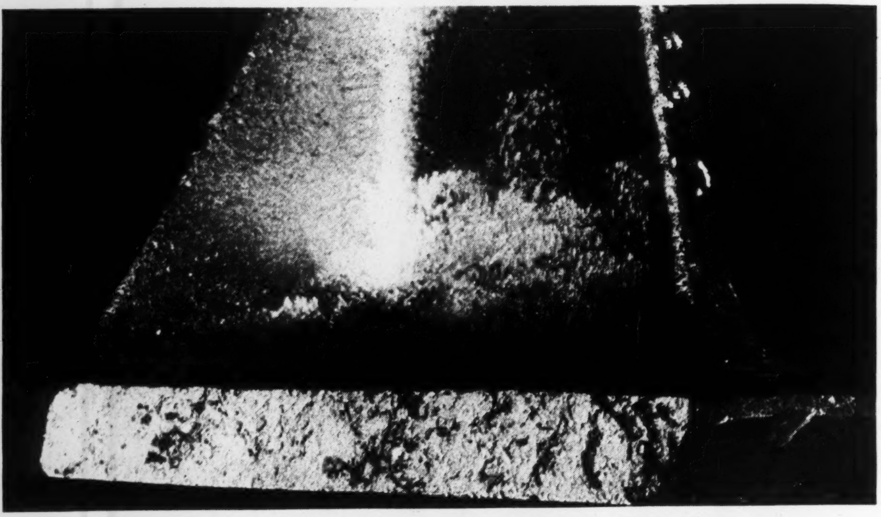


FIG. 10.—Fracture of Poorest Corner Seen in Fig. 9 (*c*).

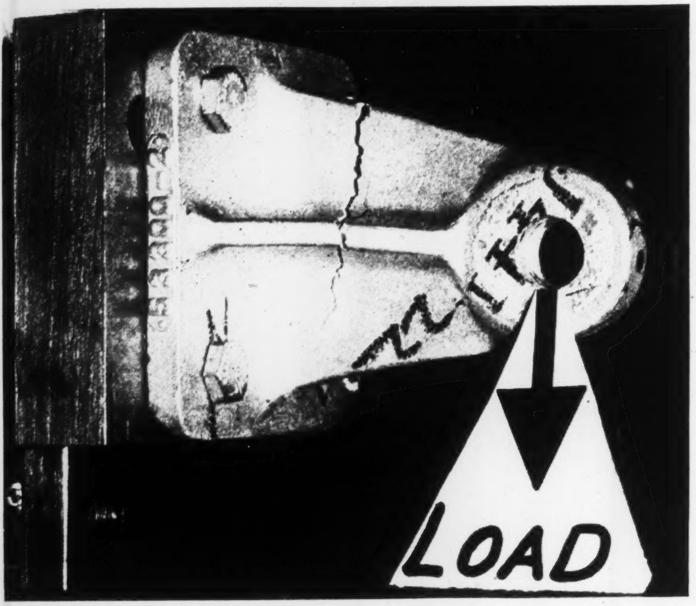


FIG. 11.—Method of Testing Web of Bracket; Shows Type of Fracture.

as 1 or 2 per cent or less can usually be detected. The fact that the fatigue strength is greatly reduced with notches, or what are sometimes called "stress-raisers," is well known; but the effect of "stress-raisers" on static tests is not well known. Considerably more work like that of Matthaes needs to be done before the effect of "stress-raisers" on static tests will be completely understood.

TESTS ON CASTINGS

A comparison between radiographic testing, static tension testing, and impact tension testing was carried out with a heat-treated aluminum-copper casting alloy (195-T4) with approximately the following chemical analysis:

Copper, per cent	4.45
Iron, per cent	0.66
Silicon, per cent	0.84
Zinc, maximum, per cent	0.03
Magnesium, maximum, per cent	0.03
Manganese, maximum, per cent	0.03
Others, per cent	0.03
Aluminum	balance

These again were taken from certified test records as furnished by a large producer of this material. The samples for test were sand-cast hinge brackets selected at random from several routine Lockheed Aircraft production orders. The source of the material and foundry procedure was that of a large reliable concern. The mechanical test used for this investigation was a combination of bending plus shear, as indicated in Fig. 7. From the loads required to break these castings, the shear strength was calculated in the following manner: the load at failure was divided by the cross-sectional area at the point of support, thus giving an average shear stress. This method of calculating the strength was used because the thickness of the castings varied enough so that some method was necessary in order to take this effect into account. Since the tests were conducted in order to determine the *relative* strength of the parts and not the *absolute* strength, this method is satisfactory. The results obtained from these calculations are plotted in Fig. 8. The arbitrary scale of quality used in Fig. 8 is not the same scale as that employed for wrought material. For castings, the arbitrary values of radiographic quality from 1 to 4 are shown in Fig. 15 (*a*) and (*b*), Fig. 15 (*a*) being that of radiographic quality No. 4 and (*b*) being that of Nos. $2\frac{1}{2}$ and 3. Figure 16 shows radiographic quality No. 1.

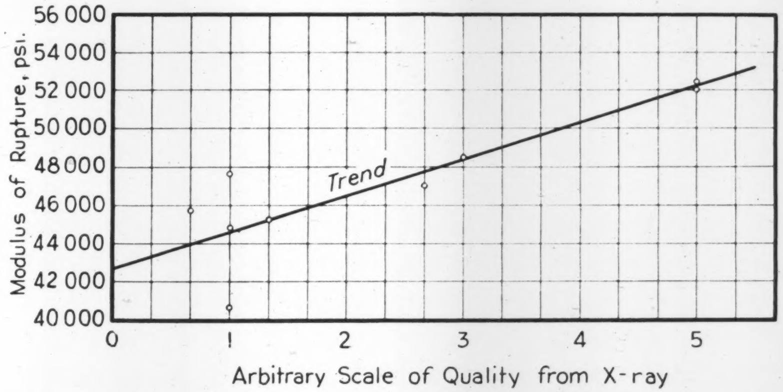


FIG. 12.—Correlation Between Static Tests of Bracket Castings and X-ray Tests.

The approximately linear relation between static tests and X-ray quality

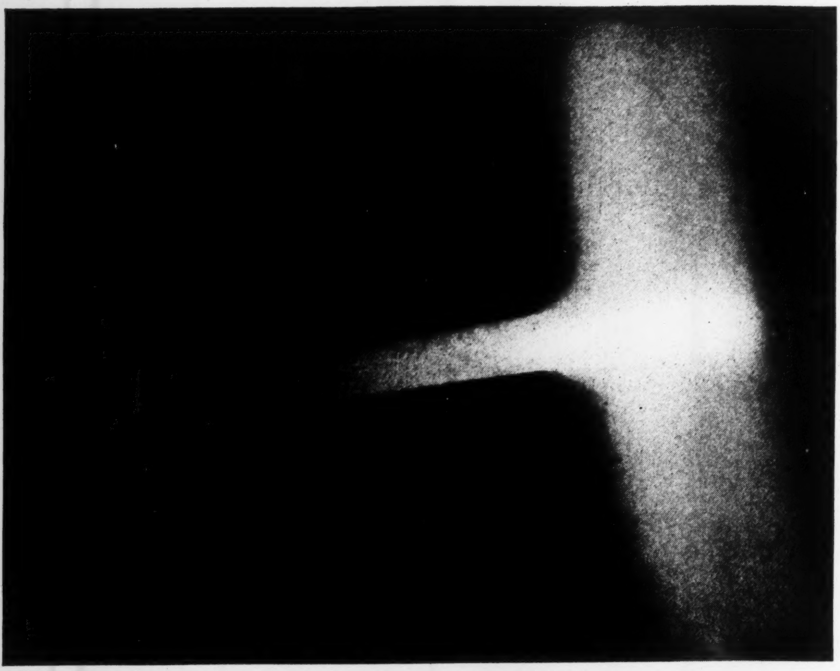


FIG. 13.—Radiograph of Fair Web Material.

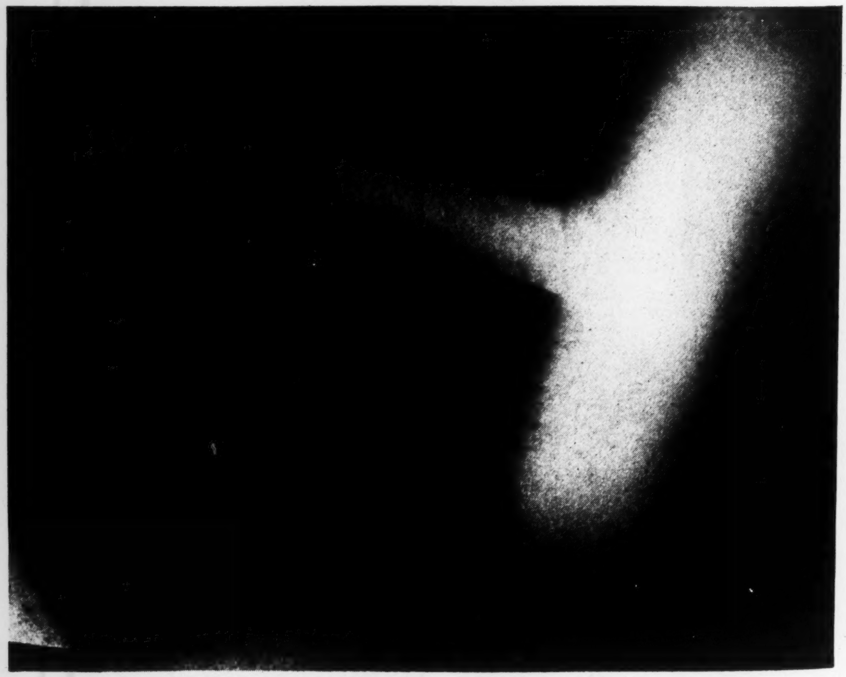
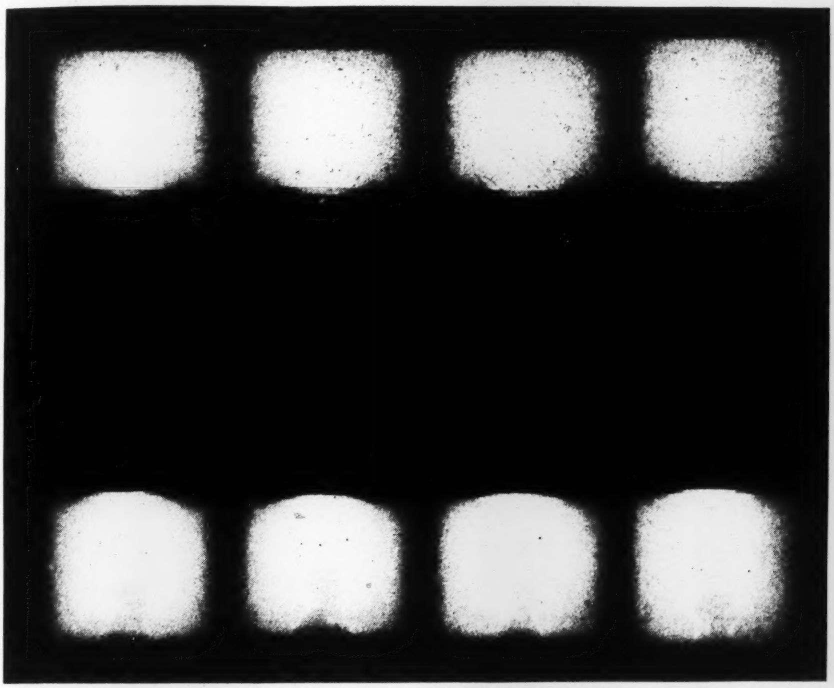


FIG. 14.—Radiograph of Bad Web Material.



(*a*) Good tension impact specimen (diameter equals ¼ in.).

(*b*) Medium tension impact specimen (diameter equals ¼ in.).

FIG. 15.—Arbitrary Values of Radiographic Qualities.

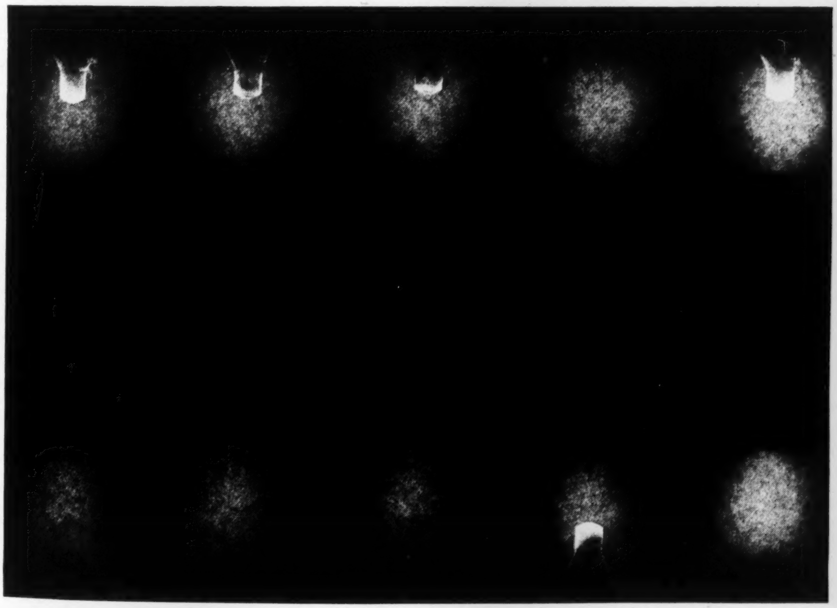


FIG. 16.—Radiograph of Bad Tension Impact Specimen (Diameter Equals ¼ in.).

shown in Fig. 8 is encouraging in spite of the above mentioned insensitivity of static tests. Obviously the X-ray testing was conducted first, and all corners were rated before any static tests were made. It might be mentioned that correlation as good as that indicated in Fig. 10 can probably be obtained only on materials like the present castings, which have their imperfections more or less uniformly distributed. In this particular case, shrinkage porosity is fairly uniformly distributed, as shown in Fig. 9 (*a*) and (*b*)—Fig. 9 (*a*) being a better casting, or showing less shrinkage porosity. Figure 9 (*c*) shows some blowholes in addition to the general porosity. Upon failure, the poorest corner in Fig. 9 (*c*) revealed the fracture shown in Fig. 10, the dark spots seen in this photograph being places where the fracture went through blowholes. The dark cluster near the center is the edge of the large blowhole shown in Fig. 9 (*c*).

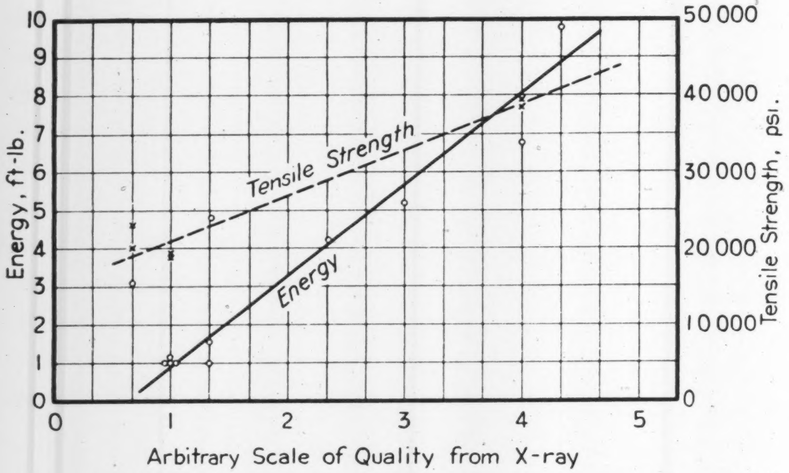


FIG. 17.—Correlation of Static and Dynamic Tension Tests with X-ray Tests.

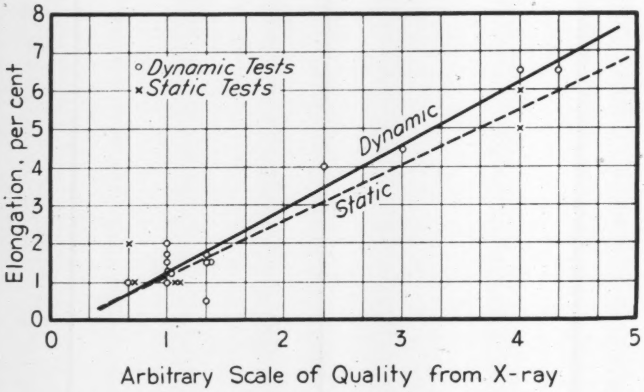


FIG. 18.—Correlation of Elongation Under Static and Dynamic Tension Tests with X-ray Tests.

Other brackets of the same kind were tested in a manner simulating the conditions which would be encountered in service as shown in Fig. 11. From the loads required to break the castings, the modulus of rupture was calculated as follows: for each piece the thickness and the height of the section at the point of fracture was measured; from these measurements the moment of inertia of the section at the point of fracture was calculated. Then by using the well-known equation

$$\text{Stress } \sigma = \frac{My}{I}$$

the modulus of rupture was obtained. M equals the load multiplied by the perpendicular distance to the point of fracture, and y and I are obtained by the above-mentioned measurements. The arbitrary scale of quality as shown in Fig. 12 is the same as that used in Fig. 8. Again, a linear relation is revealed between static bending tests of the bracket web and X-ray tests. It should be noticed that the variation in static strength is about 16 per cent. Figures 13 and 14 are samples of good and bad castings, respectively.

In order to carry this correlation of X-ray with mechanical tests on castings further, test bars of 195-T4 alloys obtained from the same source of supply as the bracket castings were radiographed and tested in both static and dynamic tension tests. Before testing, the bars were machined to conform to dimensions given in Mechling and Jack's paper for tension impact specimen. Both the static and the dynamic tests were made on the same type of specimen, in order to reduce the number of variables. The radiographs of sample bars are given in Figs. 15 and 20. The results are plotted in Figs. 17 and 18. The radiographic quality is the same for these bars as used for the other castings.

In these figures, it is seen very distinctly that the tensile strength, impact energy, elongation in static tests, and elongation in dynamic tests are linear functions of radiographic quality on the arbitrary scale which was selected before the mechanical tests were made. However, the change in tensile strength is much smaller than that of the tension impact energy for a given change in radiographic quality. The ultimate strength varied by only a factor of 2, whereas the energy varied by a factor of 10. This is in agreement with what one would expect from the results of Matthaes mentioned above. It is very interesting that the correlation between static and dynamic elongation with X-ray quality is so close.

From these results, it would appear that good correlation should be obtained between X-ray tests and fatigue tests, for this is also a dynamic test. This point has not as yet been completely investigated, but results to date indicate that the above contention will be substantiated.

Conclusions:

These results show that correlation has been obtained between the nondestructive X-ray tests and destructive mechanical tests. Material judged "good" or "poor" from radiographic tests, when compared by dynamic tests show a greater difference than when compared by static tests.

DISCUSSION

Mr. J. M. Lessells[1] (*presented in written form*).—This paper is of considerable interest in regard to the type of fractures which are obtained and correlated with radiographic records. The fact that some correlation between the wavy appearance in the photographs appearing in the paper and the fibrous type of fracture seems to be of considerable importance. Probably the term "fibrous" is badly chosen, because from the usual terminology "fibrous" is associated with good characteristics, namely, toughness or ductility, such as in wrought iron. Here fibrous means less than this and the term "woody fracture" might be better.

We recently were discussing "sliding failures" and "separation failures," and possibly the work of the authors on aluminum alloys can be interpreted to show a manifestation of these effects. It would be of interest to know whether a close examination of the two types of failures show any difference in the path of the fracture through the material. Although the tension impact test may be a promising one, it might be better if the authors retain the better-understood tests as a basis for their comparison.

It is to be hoped that the authors will continue this line of investigation, the importance of which seems to be very great indeed.

Mr. E. H. Dix, Jr.[2]—This paper, presenting valuable information on a method of testing aircraft materials, should be of great interest, for anything that can be done to improve the uniformity of aircraft materials or, for that matter, any engineering material, is of importance. Radiographic examination in the development of improved foundry methods for making high-quality aluminum castings is old. It has been proven a valuable research and development tool. This paper attempts to carry the use of this method a step further and it is necessary to examine the data critically to determine whether or not this next step is ready for industry. However, my discussion will deal not so much with the radiographic data presented but, rather, with the engineering implications which may be drawn from these data and the method of presentation.

I hope to clarify my discussion by differentiating clearly between the three subjects discussed in the paper: first, the significance of the wavy appearance shown in the radiographs of some 14S-T forgings; second, data presented in connection with another wrought alloy—24S-T; and, third, radiographic examination and mechanical tests of castings.

In the case of the 14S-T forgings, the authors clearly state the number of different billets which have been used in arriving at their conclusions. However, where a correlation is attempted, it is always helpful to know how many items fall in the different classifications given. For instance, these 32 forgings of 14S-T have been rated by means of radiographic examination and, on the basis of presence or absence of wavy structure, classified as good, fair, and bad. For the reader to form an appraisal of the dependability of the correlation between radiographic examination and mechanical properties it would be helpful to know how many of these 32 forgings fell into each of the three classes. Likewise, since the thickness of the forgings varied from $\frac{1}{2}$ in. to 4 or 5 in., it would be of interest to know what percentage of the material of the different thicknesses fell into the three groups.

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[1] Associate Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

[2] Chief Metallurgist, Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pa.

From an engineering standpoint, in Fig. 6 of the paper, the static properties are above the ANC specification except the elongation across grain. The ANC specification refers to material up to 4 in. in thickness or diameter, but does not go into detail as to how the test should be made. However, the following quotation from the Federal Specification for Aluminum—Alloy; Forgings, Heat-treated, QQ-A-367, is pertinent:

> F-2*a*.—When practicable, test specimens shall be taken from a full-size prolongation of the forging in such a manner that the *axis of the test specimen is parallel to the direction of maximum flow* of the metal.
>
> F-2*c*.—When it is impracticable to provide a prolongation for test purposes, test specimens shall be cut from forgings selected from the lot by the inspector. *The longitudinal axis of the test specimen shall be parallel to the flow lines of the forgings.*

Thus it is evident that the ANC values are intended to cover with-grain specimens only.

The authors state that the elongation is the only static property which approached the amount of variation found in the dynamic properties, yet they fail to present elongation values in their graph, giving only tensile and yield strengths for the forgings which they have given ratings of good, fair, and bad. The plot of elongation values would be helpful.

Another point, perhaps of minor interest, is that comparison of Figs. 3 and 4 indicates that they cannot be "natural size"—either one is enlarged or the other is reduced. This should be clarified. Again, at the top of page 752, the authors mention the results of mechanical tests on "many" hand-forged billets of 14S-T. It would be interesting to know roughly how many. What the authors consider many, some others might not. Some numerical figure should be given.

In connection with the studies made of 24S-T, the following statement is made. "The 24S-T shown had a variation in grain size which was found by radiographic inspection." The writer does not know how a direct determination of grain size of a wrought material can be made by radiographic inspection. X-ray diffraction or metallographic methods are generally used. The method used would be of value.

While still discussing wrought materials, the authors, on page 758, discuss the sensitivity of radiographic examination to changes in cross-section such as might be induced by porosity or a blowhole. Such cavities are not normally found in wrought materials, and perhaps this discussion had better been given in connection with the radiographic examination of castings.

Lastly, referring to castings and again looking at the engineering implications, the authors broke the corners off the castings with a combination of shear and bending. They explain that it was not true shear and their calculation was made just to give a relative comparison. However, Fig. 8 is labeled "average shear stress." Thus, it is open to misinterpretation, for a person looking only at the graph would take these figures for the actual shear strength of the casting. Also, in a similar graph (Fig. 12), the authors give numerical values for the modulus of rupture, these values varying with the X-ray rating. It would be valuable to know the modulus of rupture for which these castings were designed. In other words, the worst rating here may be four or five times the design value, including factors of safety. Generally, when castings are used, the factor of safety is much larger than in the case of wrought materials.

It is unfortunate that the radiographs reproduced in Figs. 15 and 16 have been so exposed that the variations in density of the grip ends of the test bars are revealed, whereas those of the smaller gage diameter are not shown. Of course, any reproduction of radiographs is at best very unsatisfactory.

On page 762 there is a statement that the correlation shown in Fig. 8, between radiographic examination and static tests on brackets, is encouraging in spite of the previously mentioned insensitivity of the static tests. It has long been the practice to make static breakdown tests and impact tests on castings to determine their suitability for a specific application. In making such tests, care is taken that the parts are loaded as they will be loaded in service. In most instances the static breakdown tests have been shown to be entirely adequate.

MR. R. J. FRICK.[3]—There has been a little discussion on the relation of tension impact and X-ray testing. In some recent work at Kansas State College, we went over the more common types of tests and found that the tension impact was most suitable in a comparison of destructive testing and X-ray testing. One hundred welded specimens were X-rayed and then prepared for tension impact testing. It was found that the nature of failure was correctly indicated from the X-ray in 98 per cent of the cases, that is, we were able to tell from the radiograph whether failure would occur in deposited metal or parent metal. The tension impact value is a function of the volume of the section under stress, and since the radiograph will show any lack of volume of metal or voids, the two tests worked well in correlation of weld quality.

MR. W. L. HOWLAND.[4]—Mr. Triplett and I feel that to a certain extent we have done a little pioneering in this paper. We hope it is realized that like a great many pioneers we may make some mistakes and erroneous conclusions along with a few contributions. I will try to answer a few of the questions which Mr. Dix asked. In the first place I might mention that Mr. Triplett and I definitely apologize for the fact that a large amount of detail has been omitted from this report. The reason is that this work has gone on in the face of such a fast growing industry that it is with great difficulty we find time to do any research at all, and time has not been available for great care in preparing this report.

Mr. Dix expressed interest in how many tests were good, fair and bad. Obviously in the aircraft industry the engineer is looking for perhaps one bad piece in a hundred, and it is very desirable that not even one bad piece which is highly stressed get into an airplane.

The material for these tests were selected from routine examination of a very large number of parts (approximately 300).

X-ray diffraction patterns were made of material with this wavy appearance and a definite difference in the diffraction pattern was obtained between the good and the bad material.

MR. TOM A. TRIPLETT.[5]—I wish to thank Mr. Lessells for his comments;

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[3] Graduate Research Assistant, Department of Shop Practice, Kansas State College, Manhattan, Kans.

[4] Assistant Director of Research, Guggenheim Aeronautics Laboratory, California Institute of Technology, Pasadena, Calif.

[5] X-ray Metallurgist, and President, Triplett & Barton, Inc., Burbank, Calif.

I feel that these points have added to the value of the paper. I agree that the term "fibrous" was badly chosen and the term "woody fracture" would be more nearly correct.

We used the tension impact test because of the growing interest in this method on the Pacific Coast and also, since we believe that in the future, it will be of much more definite value than some of the other types of impact tests. However, as the paper indicated, we also made the better known impact tests in addition to the tension impact tests. I can assure Mr. Lessells that we are going to continue this line of investigation as we feel it has great importance.

Mr. Dix states that the radiographic examination has been proven a valuable and important development tool. Our attempt is definitely to carry the use of this method a step further, as we feel that the industry is not only ready but waiting for this step.

In the case of 14S-T forgings, Mr. Dix would like to know how many of the 32 forgings fell into each of the three classes—good, fair and bad. Our data sheets show that there were only one good, twenty fair, and eleven bad. He also expressed the desire to know the percentage of thickness that fell into the three groups. The answer is: 60 per cent of the bad material was found in 2 in. or thicker forged billets, the remaining 40 per cent from 2 in. down to ½ in.

In answering Mr. Dix's comments on ANC specifications, these called for a test specimen to be made parallel to the direction of the maximum flow of the metal. All our tests included at least six or more specimens taken in this manner. However, due to the fact that we are very near to the aircraft industry, we have found that various parts of forgings are not always loaded or stressed in a direction parallel to the direction of maximum flow of metal. Therefore, test specimens were not only taken with the grain, but across the grain as well as several directions normal to the grain.

We purposely left out the elongation values found in the static tests because in only one case did they approach the minimum (in the good specimen, mentioned above) specified values of the ANC Handbook, even in the with-grain direction. This one specimen fell short by 0.5 per cent.

Mr. Dix would also like to know approximately how many of the mechanical tests the hand-forged billets cover. In checking data sheets, we find they cover a total of 143 mechanical tests made.

In connection with radiographic inspection of grain size, a new technique has been developed, made possible only by having equipment capable of giving extremely high-grade detail, and inasmuch as, to my knowledge, the only three such machines available in this country are all located in the author's laboratories, it is not strange that Mr. Dix is unaware of how this determination may be made. At the present time a paper is being prepared on this technique.

There is a direct correlation between the "wavy appearance" seen in the radiograph and the grain size. This has been checked by both X-ray diffraction and metallographic methods. Mr. Lester has seen some of the diffraction pictures made and states that it is definitely large grain structure.

We cannot quite agree with Mr. Dix's statement that implies that cavities are not found in wrought materials, as our examinations during the past 3 yr. have shown pipes and several types of cavities.

In answer to Mr. Dix's comments on the average shear stress graphs that we have shown in Figs. 8 and 12, these were given in this manner to show the trend for correlation purposes and not to represent any specific design or allowable stress.

We do not consider it unfortunate that the radiographs shown in Figs. 15 and 16 have been so exposed that the variation in density of the grip ends of the test bars are revealed and those of the small gage diameter are not shown. It should be stated that the negative itself definitely covers both ranges very satisfactorily. The negative has a density range of 130 to 1, whereas the paper on which it is reproduced covers only a range of approximately 30 to 1. Therefore, when a correct exposure is made to make use of the 130 to 1 ratio it is obviously impossible to transfer this to paper print.

SOME MECHANICAL TESTS ON ALUMINUM ALLOYS 14S-T AND 24S-T

By W. B. Mechling[1] and S. S. Jack[2]

Synopsis

Mechanical tests were conducted on aluminum alloys 14S-T and 24S-T. The former alloy was in the form of a large hand-forged billet and the latter in the form of a $\frac{3}{4}$ by 6-in. rectangular bar. In addition to the determination of the usual mechanical properties, tension impact values were also obtained for both materials. Care was exercised to obtain all test specimens from the same stock and to define the condition of the material by photomicrographs and grain direction.

It was found that the results obtained compared favorably with the generally accepted mechanical properties of these alloys. Considerable variation of the mechanical properties with grain direction was found, the magnitude of these variations being shown in both tabular and graphical form.

Whereas the results obtained compare favorably with the generally accepted physical properties of these alloys, these tests present quantitatively the variation of these properties with grain direction.

In an endeavor to evaluate the tension impact test, and to correlate results, it was necessary to conduct the investigation on materials whose exact mechanical properties were known. The following alloys were chosen for investigation, since they are widely used in the aircraft industry:

14S-T a typical forging alloy
24S-T a typical alloy for rolled products

Since complete data on the mechanical properties of these alloys are in general not easily obtainable by designers, it was decided to make static, fatigue, and standard impact tests as well as those covering the tension impact values. The routine tests conducted for correlation, therefore, have an added value, inasmuch as they may present further data on these alloys.

Test Procedure

Test Specimens:

In order to obtain maximum uniformity, the specimens for each material were cut from the same billet. Photomicrographs were made of the material in three mutually perpendicular planes as a means of defining the grain structure.

Tests in which the longitudinal axis of the specimen is parallel to the grain of the material are designated as "with grain" in the tables and accompanying discussion. Those in which the longitudinal axis of the specimen is perpendicular to the grain direction are designated as "cross grain."

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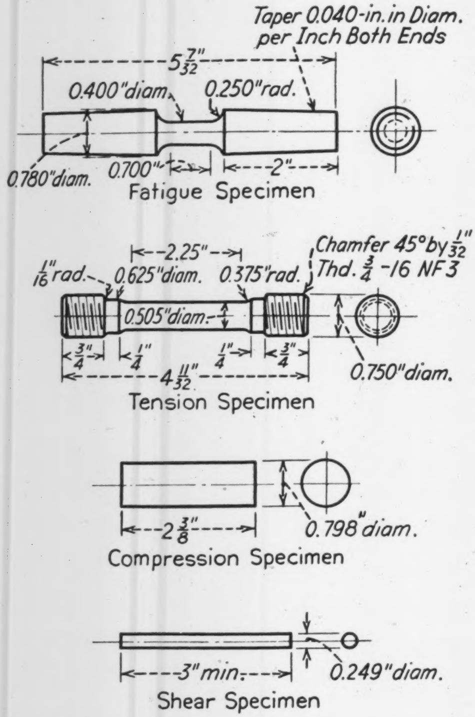
[1] Lieutenant, U. S. Navy, California Institute of Technology, Pasadena, Calif.

[2] Captain, U. S. Marine Corps, California Institute of Technology, Pasadena, Calif.


Taper 0.040-in. in Diam. per Inch Both Ends
5 7/32"
0.400"diam.
0.250"rad.
0.780"diam.
0.700"
2"
2.25"
Chamfer 45° by 1/32"
Thd. 3/4 -16 NF3
1/16" rad.
0.625"diam.
0.375"rad.
0.505"diam.
3/4"
1/4"
1/4"
3/4"
4 11/32"
0.750"diam.
2 3/8"
0.798"diam.
3" min.
0.249"diam.

Fatigue Specimen

Tension Specimen

Compression Specimen

Shear Specimen

FIG. 1.—Details of Test Specimens.

The first three tests were made in the research laboratories of the Douglas Aircraft Co., and the remainder were made in the structures laboratory of the California Institute of Technology.

Static Tension:

The tension specimens (Fig. 1) were tested in a Baldwin-Southwark 40,000-lb. capacity machine. The ends of the specimens were attached to spherical-end fittings used in the testing machine for tension tests. In order to be certain that there was no bending in the test, two Huggenberger type extensometers were attached diametrically opposite and their readings compared. The average strain readings of the extensometers were used as the strain of the specimens.

Shear:

The shear specimens (Fig. 1) were made to fit a standard rivet shear block. This method of testing places the specimen in double shear, and the character of the failure indicated that there was no bending in the test. These tests were also conducted with the Baldwin-Southwark machine.

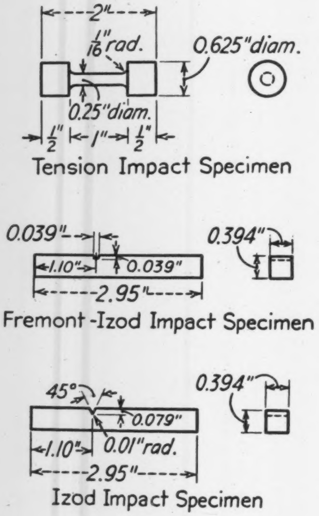
Compression:

The compression specimens (Fig. 1) were tested in the Baldwin-Southwark machine. They were placed between spherical ends to eliminate bending.

Fatigue:

Fatigue tests were conducted on a machine which is essentially a rotating-cantilever-beam type with a speed of rotation of approximately 3000 r.p.m. The method of loading the specimen introduced direct compressive stresses but of such magnitude as to be considered negligible, as in no test did the ratio of direct compressive stress to maximum bending stress exceed 0.002.

Maximum stress in the specimen was


2"
1/16" rad.
0.625"diam.
0.25"diam.
1/2"
1"
1/2"
0.039"
0.394"
1.10"
0.039"
2.95"
45°
0.394"
0.079"
1.10"
0.01"rad.
2.95"

Tension Impact Specimen

Fremont-Izod Impact Specimen

Izod Impact Specimen

FIG. 2.—Details of Impact Test Specimens.

computed in accordance with the formula for a simple beam in bending:

$$\sigma = My/I$$

where σ = maximum stress,
M = applied bending moment,
y = radius of specimen at the test section, and
I = moment of inertia of the test section.

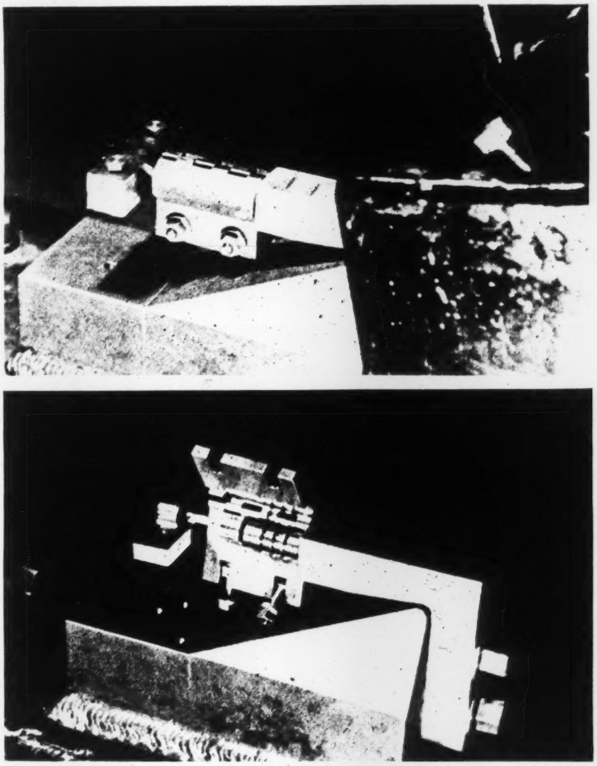


FIG. 3.—Tension Impact Specimen in Modified Anvil.

The fatigue strength of the material was defined at 10,000,000 cycles, that is, 20,000,000 reversals of stress. This limit is considered to cover the fatigue conditions encountered throughout the comparatively short life of an airplane and is sufficient to determine the effect of grain direction upon fatigue strength.

Impact Tests:

The Izod (notched-bar) impact specimens (Fig. 2) were tested in a standard Olsen 120 ft-lb. capacity impact machine whose maximum striking velocity was 11.35 ft. per sec.

Frémont-Izod impact specimens (Fig. 2) were tested in the same manner as the standard Izod type. The only variation in the specimens was in the form of the notch at the section of fracture.

Tension-impact specimens (Fig. 2) were tested in the Olsen impact machine. The fixed anvil was modified to hold the tension-impact specimen horizontally and in such position that the hammer would strike the movable anvil at the exact bottom of the stroke (Fig. 3). The determination of energy absorbed in breaking the specimen was made in the normal manner.

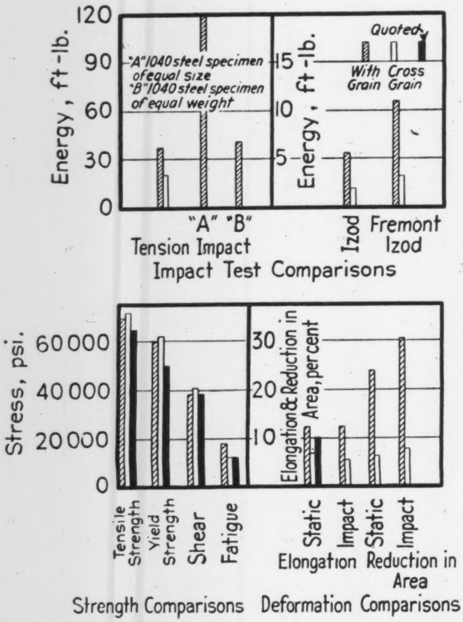


FIG. 4.—Comparative Mechanical Properties of 14S-T.

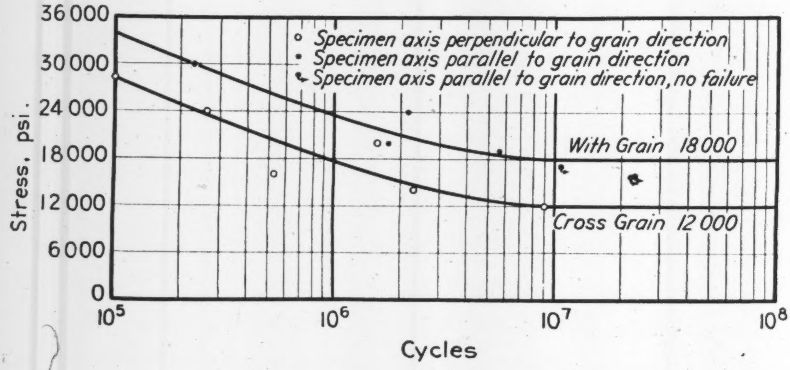


FIG. 5.—Stress-Cycle Diagram for 14S-T.

A number of preliminary tests were made in order to determine the effect of surface condition and specimen size on the tension-impact values. Impact values were obtained on specimens which were rough machined, smooth machined, ground, and ground and polished, in order to determine, if possible, the effect of surface conditions on the impact values. It was found that all specimens with a smooth machine finish, or better, absorbed the same amount of energy, the variations lying within the variations encountered in a group of specimens with a given finish. It was therefore concluded that a smooth machine finish was satisfactory for tension-impact specimens.

When specimens having different body diameters were tested, it was found that for diameters equal to or greater than 0.25 in. the unit energy (ft-lb. per cu. in.) absorbed remained constant. It was therefore decided to use a 1-in. long by 0.25-in. diameter body for all test specimens.

ALUMINUM ALLOY 14S-T

The aluminum alloy 14S-T is a high-strength, heat-treatable alloy which is finding increasing favor in the aircraft industry as a material for the manufacture of highly stressed forged fittings. It is sometimes furnished to the manufacturer in the form of a hand-forged billet approximately 5 by 5 in. in cross-section. The test specimens were cut from a single billet of this type.

TABLE I.—RESULTS OF MECHANICAL TESTS ON SPECIMENS CUT FROM A 5 BY 5-IN. BILLET OF ALUMINUM ALLOY 14 S - T.[a]

Test	Number of Specimens Tested	Specimen Grain Direction	Yield Strength, psi.		Tensile Strength, psi.		Elongation, per cent,		Reduction in Area, per cent, Test
			Test	Quoted Allowable[b]	Test	Quoted Allowable[b]	Test	Quoted Allowable[b]	
Static tension	3	With	60 000	50 000	70 300 (1%)	65 000	12.3 (19%)	10	24.3 (11%)
	2	Cross	62 500 (8%)		71 150 (3%)	65 000	6.9 (2%)		6.5 (8%)
Shear	1	With			38 760	39 000			
	1	Cross			41 060				
Compression	3	With			74 700 (2%)	65 000			
Fatigue		With			18 000	12 000			
		Cross			12 000				
			Energy, ft-lb.						
Tension impact	4	With	37.5 (15%)				12.5 (20%)		30.5 (12%)
	5	Cross	20.2 (11%)				5.7 (5%)		7.7 (43%)
Izod impact	5	With	5.6 (10%)						
	5	Cross	1.9 (21%)						
Izod Frémont impact	5	With	11.1 (13%)						
	5	Cross	3.3 (21%)						

[a] The percentages in parentheses indicate maximum variation in per cent from mean value.
[b] Strength of Aircraft Elements, Army-Navy-Commerce Committee on Aircraft Requirements.

TABLE II.—MECHANICAL TESTS ON ALUMINUM ALLOY 24 S - T.[a]

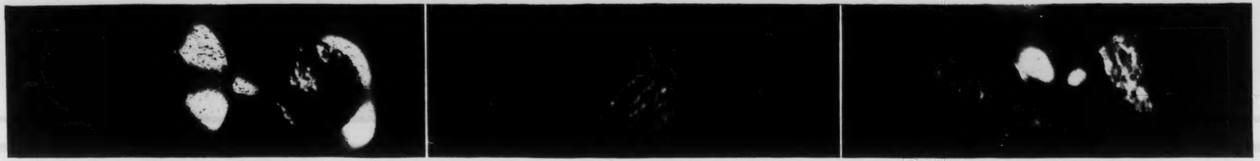
Test	Specimen Size	Number of Specimens Tested	Specimen Grain Direction	Yield Strength, psi.		Tensile Strength, psi.		Elongation, per cent		Reduction in Area, per cent, Test
				Test	Quoted Allowable[b]	Test	Quoted Allowable[b]	Test	Quoted Allowable[b]	
Static tension	Large	3	With	39 700 (2%)	40 000	65 000 (1%)	62 000	21.6 (5%)	14	21.3 (4%)
		1	Cross	40 000		63 900		14.5		13.0
	Small	3	With	50 500 (1%)	40 000	69 150 (1%)	62 000	21.4 (7%)	15	25.7 (3%)
		1	Cross	45 200		68 200		22.5		23.5
Shear	Large	6	With			42 400 (3%)	37 000			
	Small	6	With			43 060 (5%)	37 000			
Compression	Large	3	With			Over 78 000	62 000			
	Small	4	With			Over 78 000	62 000			
Fatigue	Large		With			18 700	14 000			
			Cross			18 000				
				Energy, ft-lb.						
Tension impact	Large	5	With	51.2 (8%)				18.4 (14%)		22.6 (15%)
		5	Cross	39.4 (9%)				15.3 (5%)		15.2 (25%)

Test	Specimen Size	Specimen Grain Direction	Number of Specimens Tested	Plane of Notch	Energy, ft.-lb.	Number of Specimens Tested	Plane of Notch	Energy, ft.-lb.
Izod impact	Large	With	5	Yellow	9.7 (3%)	4	Red	8.4 (5%)
		Cross	5	Blue	4.8 (14%)	2	Yellow	6.5 (10%)
Izod Frémont impact	Large	With	9	Yellow	15.8 (11%)	7	Red	13.6 (8%)
		Cross	3	Blue	10.0 (1%)	3	Yellow	11.8 (6%)

[a] The percentages in parentheses indicate maximum variation in per cent from mean value.
[b] Strength of Aircraft Elements, Army-Navy-Commerce Committee on Aircraft Requirements, January, 1938.

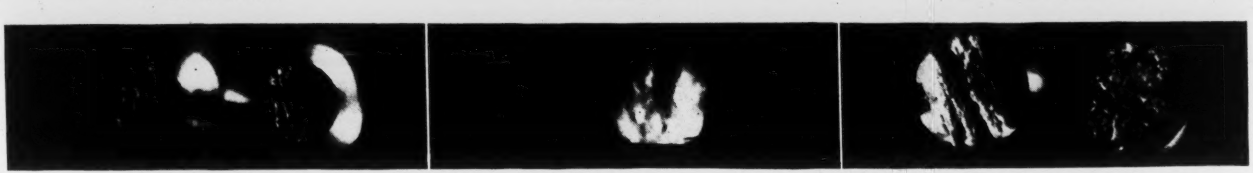
NOTE.—Specimens denoted by large grain were cut from ¾ by 6-in. stock. Specimens denoted by small grain were cut from ¼-in. plate.

With Grain.



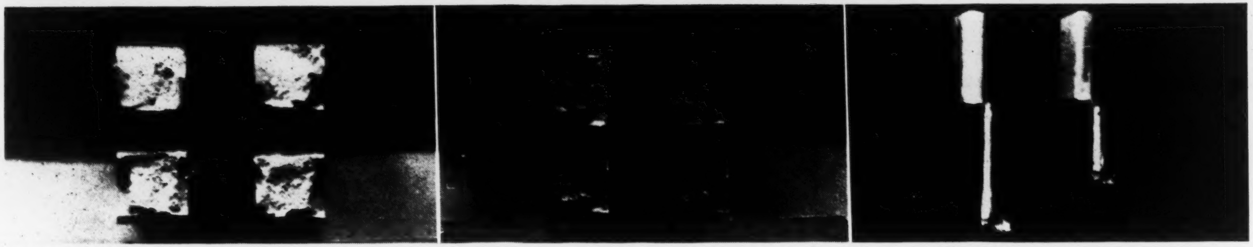
Fatigue specimen. Shear specimen. Static tension specimen.

Cross Grain.



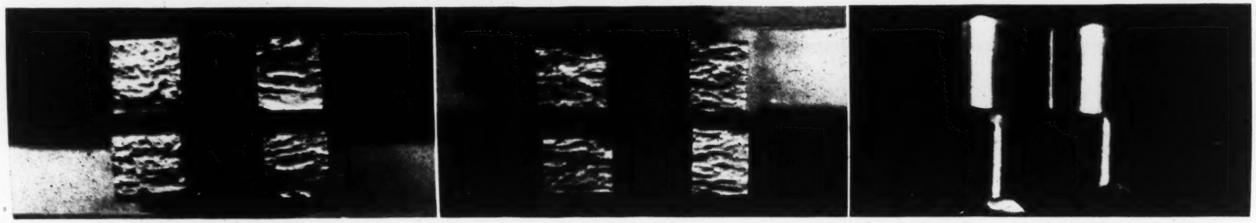
Fatigue specimen. Shear specimen. Static tension specimen.

With Grain.



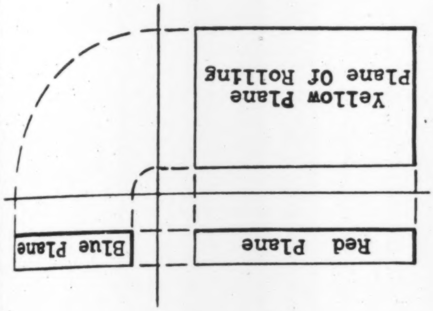
Frémont impact specimen. Izod impact specimen. Tension impact specimen.

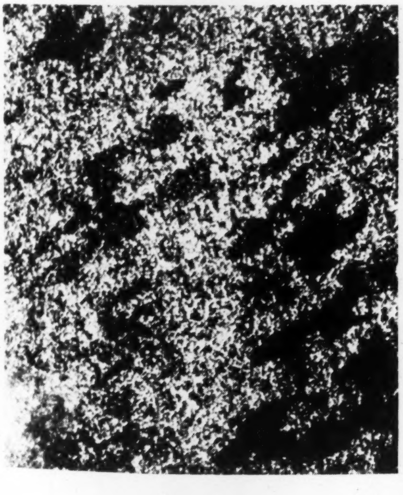
Cross Grain.



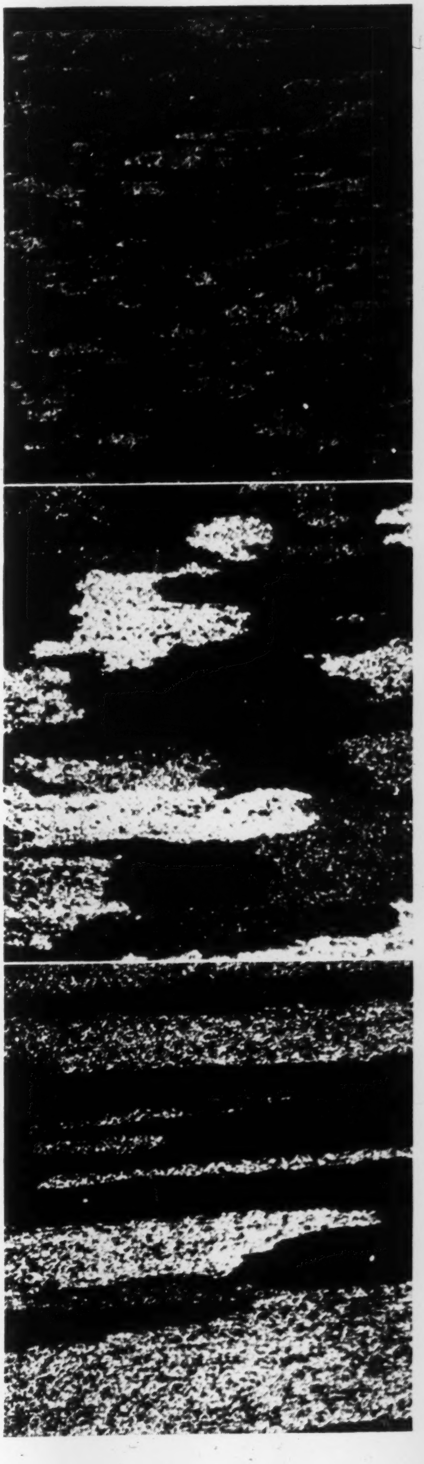
Frémont impact specimen. Izod impact specimen. Tension impact specimen.

Fig. 6.—Appearance of Fractures in 14S-T Specimens


Yellow Plane
Plane Of Rolling
Blue Plane
Red Plane



(*a*) Blue plane, large grain.



(*b*) Red plane, large grain. (*c*) Yellow plane, large grain. (*d*) Yellow plane, small grain, $\frac{1}{4}$-in. plate stock.

FIG. 7.—Photomicrographs of 24S-T (× 50).

Designation of three mutually perpendicular planes with photomicrographs of grain structure in each plane.

The test results are presented in both tabular and graphical form (Table I and Figs. 4 and 5). They indicate that the quoted values of physical properties of 14S-T were readily obtained except for static elongation in the cross-grain direction, but the serious reduction of energy absorption in the impact tests, coupled with a decided reduction in fatigue strength in cross-grain specimens, reveals a possible quality of this alloy which should not be overlooked. Inasmuch as the cross-grain properties, as well as those along the grain, depend considerably upon the forging technique used, the strength values found in the present tests emphasize the need for extremely careful forging design if maximum structural efficiency is to be attained. The desirability of keeping grain direction parallel to principal stresses and for avoiding sharp reentrant angles is quite apparent. It is believed that this material should be used with caution if fatigue or impact conditions are to be encountered, or if the forging is very complicated and a reasonable stress analysis cannot be made.

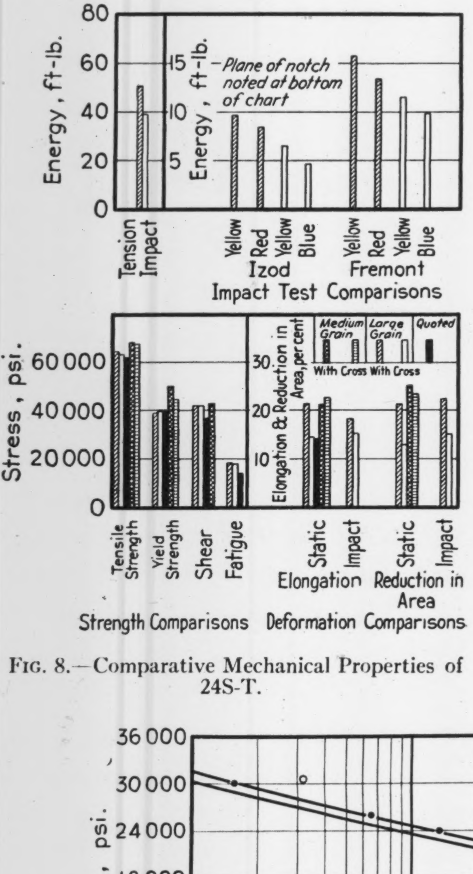


FIG. 8.—Comparative Mechanical Properties of 24S-T.

Figure 6 is a series of photographs showing the fibrous appearance of the cross-grain fracture as compared to the velvety appearance of the with-grain breaks. This difference is noted for all the types of test specimens shown, and is characteristic of breaks in the two directions which were obtained in the tests.

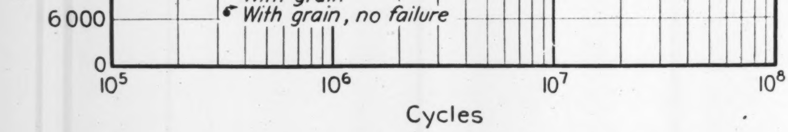


FIG. 9.—Stress-Cycle Diagram for 24S-T.

ALUMINUM ALLOY 24S-T

Alloy 24S-T is also a high-strength, heat-treatable alloy in common use in

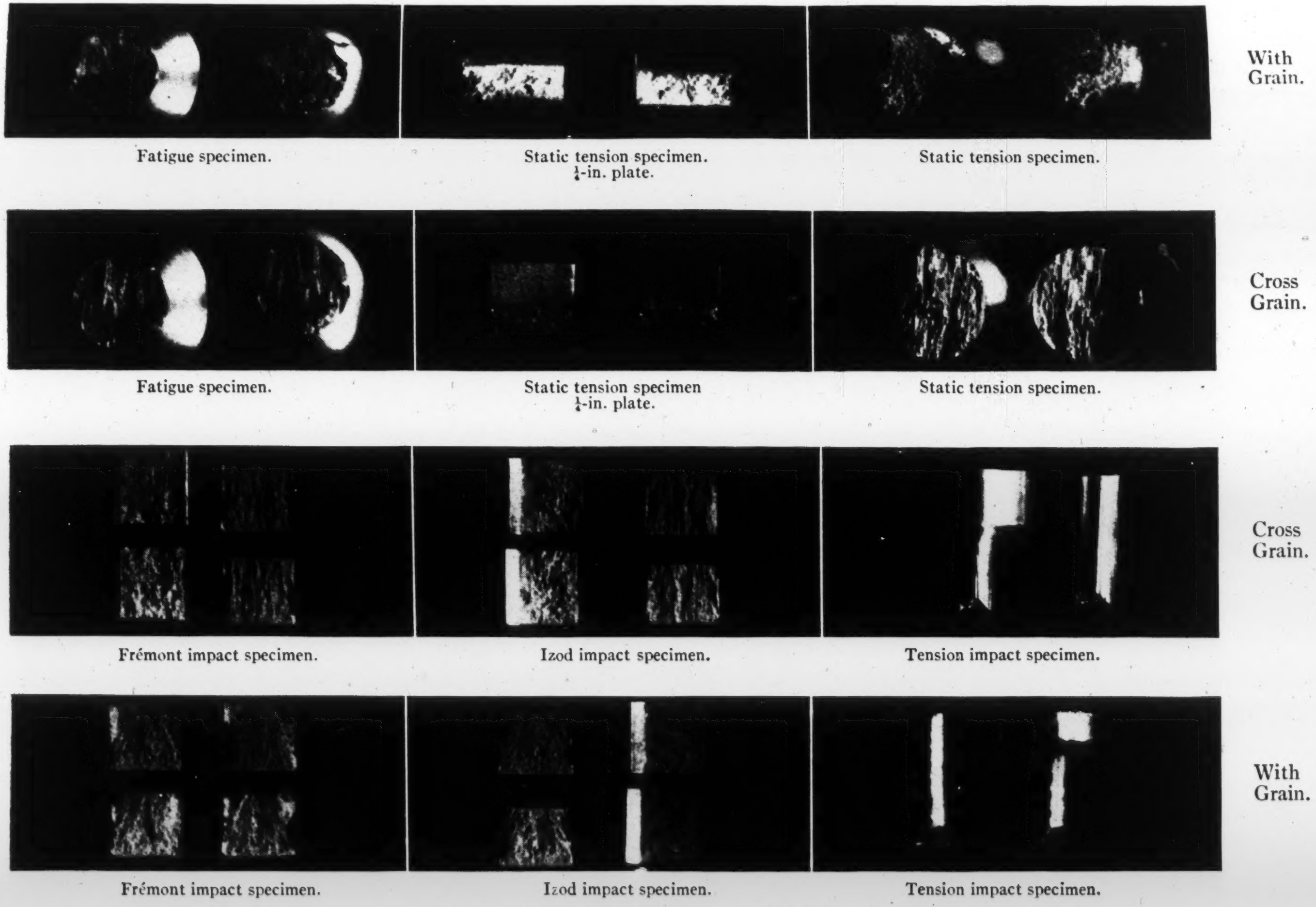

With Grain.
Fatigue specimen.
Static tension specimen. ¼-in. plate.
Static tension specimen.
Cross Grain.
Fatigue specimen.
Static tension specimen ¼-in. plate.
Static tension specimen.
Cross Grain.
Frémont impact specimen.
Izod impact specimen.
Tension impact specimen.
With Grain.
Frémont impact specimen.
Izod impact specimen.
Tension impact specimen.

FIG. 10.—Appearance of Fractures in 24S-T Specimens.

the aircraft industry in the form of sheet, bar, extrusions, and tubing. One complete set of test specimens was made from $\frac{3}{4}$ by 6-in. rectangular bar stock. In addition, a number of static test specimens were made from $\frac{1}{4}$-in. plate for the purpose of determining the effect of working on certain mechanical properties. The photomicrographs (Fig. 7) indicate the grain sizes and give color designations to the three mutually perpendicular planes of the $\frac{3}{4}$ by 6-in. bar stock. One photomicrograph showing the grain size of the $\frac{1}{4}$-in. plate stock is also included for comparison.

The test results are presented in tabular and graphical form (Table II and Figs. 8 and 9). A comparison of tension-impact values shows that this material maintains its energy absorption ability to a high degree in the cross-grain direction. The notch sensitivity tests indicate that the energy varies not only with grain direction but also with the plane in which the notch is maintained. Strength comparisons show clearly the improvement in tensile strength and yield point due to working of the material. Figure 10 shows the variation in the appearance of the fractures with and across the grain. Here, as with the 14S-T alloy, the cross-grain breaks are fibrous and laminated in nature, while the with-grain breaks have a smooth, velvety appearance.

CONCLUSIONS

The purpose of this paper is primarily to point out certain trends in the mechanical properties of two of the aluminum alloys extensively used in the aircraft industry. It is realized that the mechanical properties found are only strictly applicable to the sizes of material from which the test specimens were made. However, the reduction in physical properties in the cross-grain direction and with increasing grain size give general trends that might be expected from all sizes of stock.

The specific mechanical properties given in Table I and Fig. 4 and Table II and Fig. 8 are presented in the hope that they will fill some of the gaps in the designers' knowledge of these two materials. Further tests are contemplated, particularly those dealing with the tension fatigue impact values of these two materials.

DISCUSSION

Mr. F. M. Howell[1] (*presented in written form*).—Interesting data on the directional properties of wrought materials have been presented by the authors of this paper. Although in this case the tests are confined to aluminum alloys, similar characteristics are to be expected in varying degrees in all wrought products regardless of material.

The authors' test results reaffirm the necessity for exercising care in designing forgings to obtain maximum structural efficiency. The desirability of maintaining the grain direction parallel to the principal stresses, and for avoiding sharp reentrant angles in forgings, cannot be emphasized too strongly. Existence of the directional variation in mechanical properties of wrought products is common knowledge to metallurgists and is usually given due consideration by aircraft designers.

It seems not out of place to point out that the allowable values quoted from the ANC. Handbook,[2] "Strength of Aircraft Elements" do not apply to forgings as large as the 14S-T billet discussed in this paper. The handbook specifically states that the values given apply only to forgings up to 4 in. in diameter or thickness. Very few of the die forgings of 14S-T alloy supplied to the aircraft industry contain sections even as large as 4 in. in thickness, and only a small percentage of parts are machined from hand-forged 5 by 5-in. billets.

Similarly, most of the 24S-T alloy sheet, extrusions, and tubing used in the aircraft field is much thinner than the $\frac{3}{4}$ and $\frac{1}{4}$-in. stock used in these tests.

Appreciating the necessity for the use of certain machined fittings where dies are not available, a tremendous amount of research work has been put on the problem of improving the cross-grain properties of aluminum alloys during the past 3 yr. This has resulted in important improvements in the process of manufacture, which have been responsible for appreciable improvement in these properties. The improvement is shown largely by increased elongation, tests made over the last 18 months on 5 by 5-in. hand-forged billets averaging nearly 20 per cent higher in elongation in the transverse direction than was found by the authors.

The conclusions may give the impression that a greater difference between with-grain and cross-grain properties occurs in coarse-grain material than in fine-grain material. While it is true that material having a fine grain structure usually shows higher strength than one possessing a coarser grain structure, the differences between the $\frac{3}{4}$ by 6-in. rectangular bar stock of 24S-T and the $\frac{1}{4}$-in. plate of the same alloy should not be attributed solely to differences in grain size. It is largely due to the type and amount of working that the ingots received.

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[1] Engineer, Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pa.

[2] Issued by the Army-Navy-Commerce Committee on Aircraft Requirements.

SPECTRAL EMISSIVITY (AT 0.65 μ) OF SOME ALLOYS FOR ELECTRICAL HEATING ELEMENTS

By W. F. Roeser[1]

Synopsis

Determinations of the spectral emissivity of a number of commercial heating element materials were made to obtain data needed for the measurement of the operating temperature of these alloys during life tests. The spectral emissivity of the alloys was determined both in air and under conditions which are ordinarily considered reducing, by measuring the true temperature and the apparent temperature of the surface at the effective wave length (about 0.65 μ) ordinarily used in optical pyrometry.

The emissivity of the oxide or oxides formed on each general class of material in air was apparently definite and characteristic of that class of material. In commercial hydrogen, each of the alloys studied acquired a coating of oxide which differed in radiation characteristics from that formed in air at high temperatures. The emissivity of the oxide formed on the nickel-chromium and nickel-chromium-iron alloys in commercial hydrogen varied between wide limits (about 0.4 to 0.85) depending upon the atmosphere and the conditions of heating.

The emissivity of the nickel-chromium and nickel-chromium-iron alloys in an atmosphere of hydrogen sufficiently pure to prevent the formation of any oxide was about 0.35. Although an atmosphere was not obtained which would prevent the formation of an oxide on the iron-chromium alloys containing aluminum, the results obtained on iron-chromium alloys containing various amounts of other elements indicate that the emissivity of the iron-chromium-aluminum alloys would not differ appreciably from 0.35 if these alloys could be heated in the absence of any oxygen.

In life tests to determine the relative performance of electrical heating element materials, the operating temperature of the material probably has more effect upon the result than any other single variable. Most tests of this nature are conducted by heating the materials electrically, and in such cases the temperature of the materials (usually in the form of small wires) is most conveniently measured with an optical pyrometer. The temperature observed when an optical pyrometer is sighted upon the surface of a material heated in this way is known as the apparent temperature. In order to calculate the true temperature, a knowledge of the emissivity of the surface is required.

If a piece of metal is heated to incandescence, any scratches in the surface will appear brighter than the smooth surface of the metal. This does not mean that the temperature of the scratches is higher than that of the smooth surface, but merely that different surfaces, at the same temperature, do not emit the same amount of radiant energy. Similarly, if a hole is drilled into a piece of metal, the hole will always appear brighter than the rest of the surface. If the hole in the material is deep enough, the brightness of the hole is independent of the material and depends only on the temperature. Such a hole is called a black body and radiates the maximum amount of energy obtainable from any incandescent body at that temperature. The emissivity of a black body is taken as unity, and the emissivity of any other body is expressed as the ratio of the energy radiated by that body to the energy radiated by a black body. When this is applied to the total energy radiated, it is called the total emissivity, and when applied to the energy radiated at some particular wave length, it is called the spectral emissivity at that wave length.

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[1] Physicist, National Bureau of Standards, Washington, D. C.

The spectral emissivity E_λ, the true temperature T on the absolute scale, and the apparent temperature T_a are related by the following equation:

$$\frac{1}{T} - \frac{1}{T_a} = \frac{\lambda \log_e E_\lambda}{c_2} \quad \ldots\ldots\ldots\ldots(1)$$

where λ is the effective wave length and C_2 is the second constant in the Wien-Planck radiation law. For a wave length $\lambda = 0.65\mu$ (the effective wave length of the red screen in practically all types of optical pyrometers) and $C_2 = 2.578$ cm. deg. Fahr., the above equation reduces to

$$\frac{1}{t + 460} - \frac{1}{t_a + 460} = \frac{\log_{10} E_{0.65}}{17{,}200} \quad \ldots\,(2)$$

where t is the true temperature on the Fahrenheit scale and t_a is the apparent temperature.

In certain types of tests, an accurate value for the emissivity is not needed, but in other types of tests, it is very essential. In the A.S.T.M. standard life test (B 76 – 38)[2] each class of material is tested at a temperature which will give a life in air of about 100 hr. An accurate value of the true temperature is not essential in this test because the emissivity of all materials of the same nominal composition, heated in the same way in air, will be very nearly the same. Consequently if several such samples are heated to the same apparent temperature they will all be at the same true temperature. However, in other types of tests designed to determine the relative performance of different materials at the same temperature or of the same material in different atmospheres, a value for the emissivity of each material under each condition of test is required in order that each material may be operated at the same true temperature.

In some of the tests designed to determine the relative performance of different materials at the same temperature, a knowledge of the spectral emissivity is required in order that all the materials can be operated at the same true temperature. Suppose a nickel-chromium alloy and an iron-chromium-aluminum alloy both are operated at an apparent temperature of 2200 F. If the materials are heated in air, the nickel-chromium alloy will be operating at a true temperature of 2221 F. ($E_{0.65} = 0.89$) and the iron-chromium-aluminum alloy will be operating at a true temperature of 2246 F. ($E_{0.65} = 0.77$). However if these same two alloys are heated in an atmosphere of relatively pure hydrogen, the nickel-chromium alloy will be operating at a true temperature of 2402 F. ($E_{0.65} = 0.35$) and the iron-chromium-aluminum alloy will be operating at a true temperature of 2271 F. ($E_{0.65} = 0.68$). The results obtained from such tests would be very different from those obtained by heating the materials at the same true temperature. The data[3] available indicate that in certain types of tests in air, the life of an element may be changed 25 to 50 per cent by changing the temperature of the material by 25 F.

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[2] Accelerated Life Test for Metallic Materials for Electrical Heating (B 76 – 38), 1938 Supplement to Book of A.S.T.M. Standards, p. 75.

Data are available on the spectral emissivity[4] of a number of metallic elements and their oxides, but very little information is available on the emissivity of alloys or of the oxides formed on the alloys when heated in air. The determination of the spectral emissivity of some of the electrical heating element materials in air and in hydrogen, was undertaken at the request of the Society's Committee B-4 on Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. The cooperation of the members of this committee in providing samples of the various heating element materials is acknowledged.

Materials and Experimental Methods

The commercial heating element materials on which measurements were made included alloys of the following nominal compositions:

1. 80 per cent nickel, 20 per cent chromium.
2. 60 per cent nickel, 24 per cent iron, 16 per cent chromium.
3. 55 per cent iron, 37.5 per cent chromium, 7.5 per cent aluminum.
4. 70 per cent iron, 23 per cent chromium, 5 per cent aluminum, 2 per cent cobalt.

Samples of the materials were heated in an induction furnace coil. Each sample, about 1 in. long and $\frac{1}{2}$ in. in diameter, was suspended by means of nickel-chromium or iron wires, in a clear fused silica tube which was provided with a window and a gas inlet and outlet. In this way, the materials were heated in the absence of any refractory material which might react with the materials themselves or which might give off gases that might react with them. The silica tube was heated to some extent by radiation and convection from the heated sample, but inasmuch as the tube fitted closely into the water-cooled furnace coil, it did not attain a very high temperature.

Measurements were made on all the materials in air and in purified hydrogen. In the latter case, commercial hydrogen was purified by passing it through copper chips at about 1450 F. to combine the oxygen impurity with the hydrogen, then through magnesium perchlorate and phosphorus pentoxide to remove water vapor, and then through granular electrolytic chromium at about 1400 F. to further remove any impurities that might react with the alloy being studied. Although the hydrogen purified in this way was sufficiently free from oxygen to prevent the formation of visible oxides on alloys of nickel, chromium, and iron, it did not prevent the formation of oxide on the alloys containing aluminum. As it was felt that hydrogen purer than this would not be used in the testing of these alloys, no attempts were made to further purify the hydrogen used in this work.

A few additional measurements of emissivity were made on the 80 per cent nickel, 20 per cent chromium alloy in commercial hydrogen and nitrogen, to determine what variations in emissivity might be expected.

It will be seen from Eq. 2 that the spectral emissivity at $\lambda = 0.65\ \mu$ (red light) is obtained directly from determinations of the apparent temperature at $\lambda = 0.65\ \mu$ and the true temperature of the surface. The apparent temperature at $\lambda = 0.65\ \mu$ of the surface of a material is readily obtained with an optical pyrometer. A value for the true temperature of a surface may be arrived at in a number of ways. In the present work, the true temperature of the surface was conveniently obtained by sighting an optical pyrometer successively into small holes drilled to different depths, thus determining the temperature gradient in the sample and then extrapolating the observations to obtain the true temperature of the surface. Determinations of the spectral emissivities of graphite, platinum, and nickel in hydrogen by this method yielded results which were consistent with those obtained by other methods. The spectral emissivities of the electrical heating element materials in air were determined by this method. The spectral emissivities of these materials in hydrogen were more conveniently determined by inserting into the material a small plug of material of known emissivity. The true temperature of the surface was obtained by measuring the apparent temperature of the insert and applying the correction for its emissivity. Results obtained by using inserts of graphite, platinum, and nickel agreed (within the experimental error) with those obtained by drilling holes and extrapolating to obtain the surface temperature. The accuracy of the observations was such that emissivity values were determined to within 2 per cent of the emissivity. Consequently any spread in the individual observations greater than 2 per cent may be attributed to actual differences in the character of the surface.

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[3] F. E. Bash, *Metal Progress*, Vol. 33, p. 143 (1938).
H. E. Koch, *Electrical World*, Vol. 107, p. 32 (1937).
W. A. Kerkham, *The Electrician*, Vol. 118, p. 641 (1937).

[4] Burgess and Waltenberg, *Bulletin*, Nat. Bureau Standards, Vol.11, p. 591 (1915) (*S 242*).
International Critical Tables, Vol. V, p. 242.
H. Hoppe, *Annalen der Physik*, Vol. 15, Series 5, p. 709 (1932).

Some preliminary measurements were made to determine the variation in the emissivity caused by the finish on the surface of a material in the unoxidized state. In purified hydrogen, essentially the same value of emissivity (within 2 per cent) was obtained on samples of nickel-chromium finished (1) with a fine file, (2) with fine sand paper, (3) with rouge polishing paper, and (4) by buffing. Slight variations in the initial surface finish would not be expected to have any appreciable effect upon the emissivity of one of these alloys in air because the oxidized surface is usually much more irregular than any surface finish. The surface of each sample on which observations were made was polished with rouge paper before heating.

When a material with a bright metallic surface is heated in air, the emissivity of the surface gradually changes from a value which is characteristic of the metal to one which is characteristic of the oxide. During this period the apparent temperature of the surface increases while the temperature of the metal is maintained constant. If and when the oxide coating becomes so thick that there is an appreciable temperature gradient in the oxide, the apparent temperature of the surface will decrease while the temperature of the metal is maintained constant. As might be expected from the nature of the oxides formed on these alloys, this latter effect was not observed in the present work. The time required to establish an oxide coating which is stable at all operating temperatures, and which is of such thickness that the emissivity of the surface is independent of the thickness of the oxide coating, depends upon the temperature at which the material is heated. Consequently all the samples on which measurements were made in air were heated at 2200 F., until no change could be detected in the emissivity with time, before making any observations at other temperatures. This required about two hours for the alloys studied.

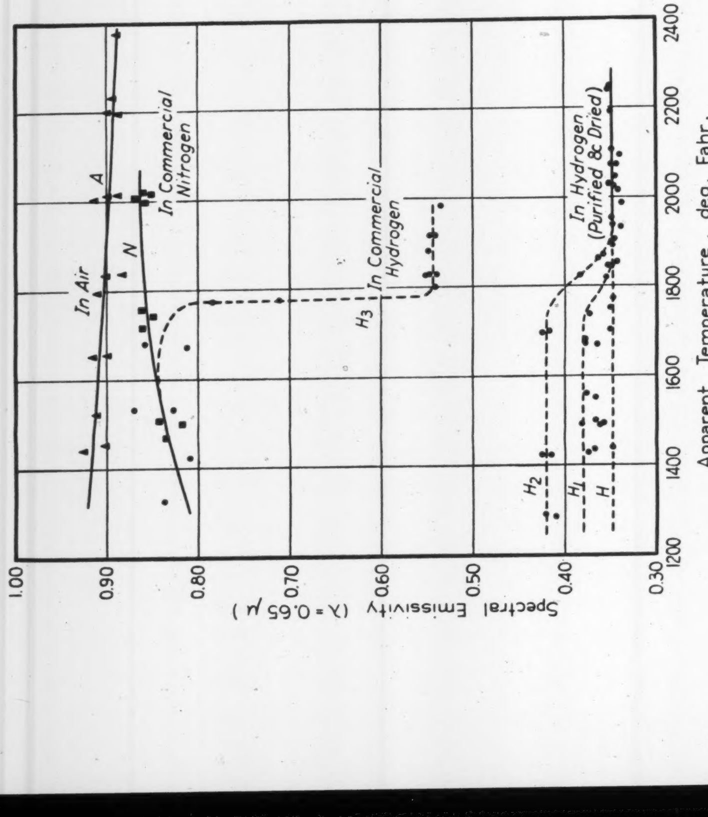

FIG. 1.—Spectral Emissivity of 80 per cent Nickel, 20 per cent Chromium Alloy in Various Atmospheres.

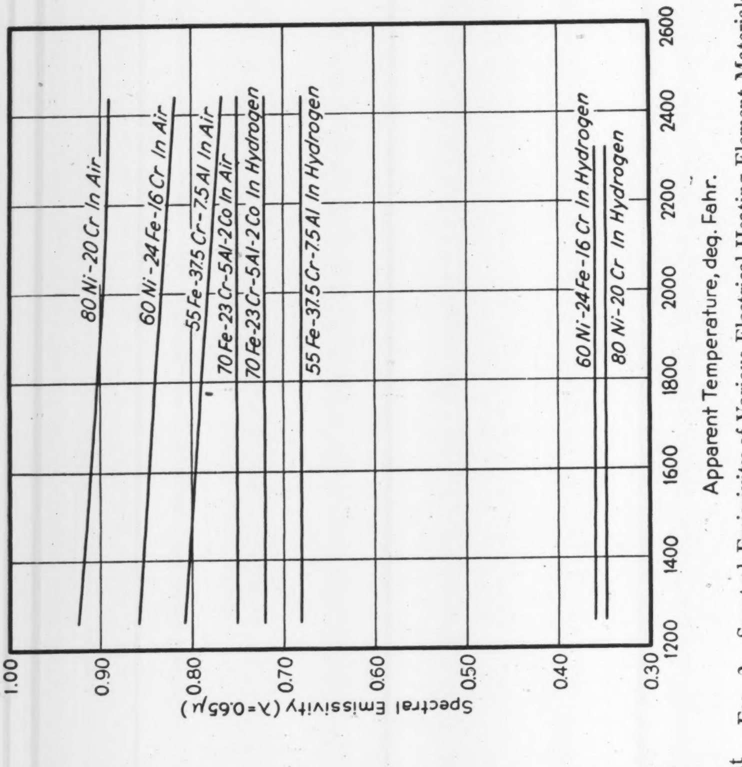

FIG. 2.—Spectral Emissivity of Various Electrical Heating Element Materials in Air and in Purified Hydrogen.

RESULTS

The results obtained on the 80 per cent nickel, 20 per cent chromium alloy under various conditions are shown in Fig. 1. Practically identical results obtained on three different samples in air indicate that the emissivity of the oxide formed on this material in air is definitely reproducible. Measurements were made on only one sample in nitrogen and only one sample in commercial hydrogen. The values obtained at temperatures above 1850 F. (apparent temperature) on a number of different samples in purified hydrogen agreed very well. However, at lower temperatures there was considerable spread in the results. In a few instances the values obtained were near curve *H*, and in these cases no oxide could be seen after cooling the metal to room temperature In the other instances the values obtained were near curve H_1 or H_2. In these cases, traces of oxide were clearly visible after cooling the metal to room temperature. The sudden change in the slopes of the curves H_1, H_2, and H_3 at about 1800 F. (apparent temperature) occurred at approximately the same temperature when heating as when cooling. The difference between the curves H_1 and H_2 is probably due to a difference in the thickness of the oxide film. The differences between these two curves and the ones marked H_3, *N*, and *A* are probably due both to differences in the thickness of the oxide and to differences in the composition of the oxide.

It will be noted in Fig. 1 that at temperatures below about 1800 F., the emissivity of the 80 per cent nickel, 20 per cent chromium alloy in commercial hydrogen (about 0.84) is not very different from that in air (about 0.91), and very much different from that in purified hydrogen (0.35).

The results obtained on the various alloys in air and in purified hydrogen are represented by the curves in Fig. 2. The surface of each specimen was polished with rouge paper before heating in a particular atmosphere. As mentioned earlier, all the alloys containing aluminum oxidized in the purified hydrogen, probably because of traces of oxygen or water vapor, or both, in the hydrogen. The observations in air were taken after heating the alloys for several hours at 2200 F. The emissivity of the oxide coating formed by this treatment was reproducible and did not vary noticeably with time. However, when the 70 per cent iron, 23 per cent chromium, 5 per cent aluminum, 2 per cent cobalt alloy was cooled to room temperature after this treatment and then heated to the higher temperatures, the same value of emissivity was not immediately obtained. This is attributed to the fact that each time this alloy was cooled to room temperature, part of a dark oxide flaked off, exposing a lighter oxide. Upon subsequent heating to the higher temperatures, some time was required for the re-establishment of the darker oxide which is apparently stable at the higher temperature.

Samples of the nickel-chromium, nickel-chromium-iron, and iron-chromium-aluminum alloys were also heated in air at about 2200 F. until a stable coating of oxide was formed and then heated in purified hydrogen at about 2200 F. After about one hour heating in the hydrogen, the emissivity of the nickel-chromium and nickel-chromium-iron alloys became constant at about 0.37. Six hours of heating of the iron-chromium-aluminum alloy in purified hydrogen produced no significant change in the emissivity. The difference between these results and those shown in Fig. 2 is attributed to the initial condition of the surface before heating in hydrogen.

The spectral emissivity of a number of

iron-chromium alloys containing various amounts of other elements was determined in relatively pure hydrogen, and it was found that the emissivity of all of these alloys (free from oxide) was approximately 0.35. It might be inferred from these measurements, that if the iron-chromium-aluminum and iron-chromium-aluminum-cobalt alloys could be maintained free from oxide at the high temperatures, their spectral emissivity would also be about 0.35.

TABLE I.—CORRESPONDING VALUES OF TRUE TEMPERATURE AND APPARENT TEMPERATURE (λ = 0.65 μ) FOR SOME ELECTRICAL HEATING ELEMENT MATERIALS.

Apparent Temperature, deg. Fahr.	True Temperature, deg. Fahr.			
	80 Ni, 20 Cr	60 Ni, 24 Fe, 16 Cr	55 Fe, 37.5 Cr, 7.5 Al	70 Fe, 23 Cr, 5 Al, 2 Co
	HEATED IN AIR			
	$E_{0.65}=0.92$ at 1400 F. to 0.89 at 2300 F.	$E_{0.65}=0.85$ at 1400 F. to 0.82 at 2300 F.	$E_{0.65}=0.80$ at 1400 F. to 0.77 at 2300 F.	$E_{0.65}=0.75$
1300	1306	1312	1317	1323
1400	1408	1414	1419	1426
1500	1509	1516	1522	1529
1600	1610	1618	1625	1632
1700	1712	1720	1728	1735
1800	1813	1823	1831	1838
1900	1915	1925	1935	1942
2000	2017	2028	2038	2045
2100	2119	2131	2142	2149
2200	2221	2235	2246	2253
2300	2323	2338	2351	2357
2400	2425	2442	2456	2461
2500	2527	2546	2561	2566
	HEATED IN HYDROGEN			
	$E_{0.65}$ = 0.35	$E_{0.65}$ = 0.36	$E_{0.65}$ = 0.68[a]	$E_{0.65}$ = 0.72[a]
1300	1386	1384	1331	1326
1400	1497	1494	1434	1429
1500	1608	1605	1538	1532
1600	1719	1716	1642	1636
1700	1831	1828	1746	1739
1800	1944	1940	1851	1843
1900	2058	2053	1955	1947
2000	2172	2167	2060	2051
2100	2287	2281	2165	2156
2200	2402	2396	2271	2260
2300	2518	2512	2376	2365
2400	....	....	2481	2469

[a] Samples of these materials oxidized in the purest hydrogen available. The values given apply for the oxide formed under these conditions.

CONCLUSIONS

The corresponding values of true and apparent temperatures for the various electrical heating element materials in air and in hydrogen, are given in Table I. The corresponding values for the nickel-chromium and nickel-chromium-iron alloys in air are accurate to about 4 deg. at 2200 F. This is equivalent to an uncertainty of about 2 per cent in the determination of the emissivity. The corresponding values for the alloys containing aluminum are accurate to about 10 deg. at 2200 F. This is equivalent to an uncertainty of about 4 per cent in the determination of the emissivity. The greater part of this uncertainty is attributed to real differences in the characteristics of the oxide or oxides formed under slightly differing conditions.

The corresponding values of true and apparent temperatures for the alloys in hydrogen apply for a particular atmosphere of hydrogen which was sufficiently free from oxygen to prevent the formation of any oxide on the nickel-chromium and nickel-chromium-iron alloys but not sufficiently free from oxygen to prevent the formation of an oxide on the alloys containing aluminum. The values for the alloys containing aluminum may be used for these alloys in hydrogen atmospheres less pure than the one used in this work, but the values for the nickel-chromium and nickel-chromium-iron alloys should not be used for these alloys in an atmosphere appreciably less pure than the one used in the determinations. Inasmuch as the values for the nickel-chromium and nickel-chromium-iron alloys apply for the unoxidized metal, they may be used for these alloys in any atmosphere which will maintain these alloys free from oxide. The results obtained on other alloys indicate that if the iron-chromium-aluminum and iron-chromium-aluminum-cobalt alloys were maintained free from oxidation at high temperatures, the corresponding values of true and apparent temperature would be essentially the same as those for the nickel-chromium alloy.

Atmospheres which are ordinarily considered reducing will not necessarily prevent the formation of an oxide on the alloys used for electrical heating elements and an atmosphere which will prevent the formation of an oxide on one class of material will not necessarily prevent the formation of an oxide on other classes of material. The emissivity of any of these alloys in such an atmosphere will depend upon the initial condition of the surface (whether oxidized or polished), the atmosphere, the temperature, and the conditions of heating. The emissivity of the surface of a material in these atmospheres may have any value between 0.35 (that of the metal) and the value in air, depending upon the composition and thickness of the oxide film. A simple way of obtaining an approximate value for the emissivity under such conditions is not available. If it is practicable, one method of obtaining an approximate value for the emissivity of the surface is to drill a small hole (which will approximate black-body conditions) in a sample of the material and sight an optical pyrometer alternately at the hole and upon the surface.

THE SPECTROGRAPHIC ANALYSIS OF TIN

By J. Warren Stewart[1]

Synopsis

Previous works on the quantitative spectrographic analysis of tin are discussed and their shortcomings indicated. The use of a large quartz Litrow spectrograph in the logarithmic sector wedge method is described. The selection of excitation conditions for quantitative analysis of the spark technique is discussed and data given concerning the general procedure. The technique used to secure uniformity and accuracy in the preparation of standard alloys is given. Selection of spectrum lines for internal standards and the preparation of working curves are discussed. Use of the working curves and some general considerations of their shape are presented. Working curves for the analysis of antimony in concentrations between 0.01 and 0.5 per cent, bismuth between 0.003 and 0.1 per cent, copper between 0.001 and 0.05 per cent, iron between 0.002 and 0.1 per cent, and lead between 0.01 and 0.5 per cent in tin are illustrated. The method used in measuring spectrum lines is described, and the accuracy of which the method is capable is considered.

When the need arose for the frequent analysis of commercial as well as especially pure grades of tin, it was decided that a spectrographic method would best fit the requirements for accuracy, speed, and ease of manipulation. Chemical methods seemed out of the question, both because they would be too time-consuming for the routine analysis of a large number of specimens and because they would not give accurate results for low concentrations of impurities.

The literature on this subject has been reviewed recently by Smith.[2] This survey disclosed that a great deal of original work would be required to set up a suitable scheme of analysis.

It was decided not to use the microphotometer for measuring spectral line intensities as described by Meggers, Kiess and Stimson[3] and also by Follett,[4] since the sensitivity of this method falls off for very low line intensities. The work of Smith,[2] who extended the methods of Gerlach and Schweitzer[5] to cover a number of impurities in tin, was inadequate since the homologous pairs of spectral lines which are the basis for this method do not continuously cover the range of impurity concentrations found in commercially pure tin. It was finally decided to follow the work done on the logarithmic sector method by Hitchen.[6]

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[1] Metals Research Laboratory, Carnegie Institute of Technology, Pittsburgh, Pa.

[2] D. M. Smith, "The Spectrographic Analysis of Tin," *Technical Publications*, Internat. Tin Research and Development Council, Series A, No. 46.

[3] W. F. Meggers, C. C. Kiess and F. J. Stimson, "Practical Spectrographic Analysis," *Scientific Papers*, Nat. Bureau Standards, Vol. 18, No. 444, pp. 235-255.

[4] D. H. Follett, "A Photometric Method Suitable for Spectrum Analysis," *Journal of Scientific Instruments*, Vol. 13, pp. 221-228 (1936).

[5] W. Gerlach and E. Schweitzer, "Die Chemische Emissionsspektralanalyse," I. L. Voss, Leipzig (1929).

[6] C. S. Hitchen, "Quantitative Estimation of the Impurities in Tin by Means of the Quartz Spectrograph," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 104, pp. 353 359 (1933) (*Technical Publication No. 494*).

Changes had to be made in the procedure, however, since many of the tins to be analyzed had impurity contents considerably below those used by Hitchen. This necessitated the collection of much original material, which is presented in the form of working curves in this paper.

The accuracy of the log sector method of analysis is well established as being within at least 10 per cent of the amount of the impurity present, which adequately satisfied present requirements.

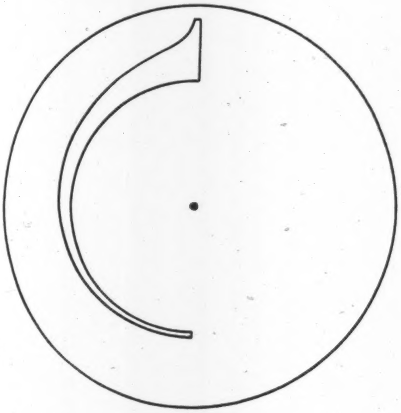

FIG. 1.—Logarithmic Sector Disk.

The method also has advantages in the ease with which measurements can be made, since it is necessary simply to measure lengths of spectral line traces on the photographic plate. The need for calibrating the photographic material is eliminated since the line intensities, as reduced by the log sector, are read at equality.

Apparatus:

The apparatus consisted of a Hilger Litrow E-1 quartz spectrograph of 130-cm. focus, a logarithmic wedge sector having a sector opening ratio of 1 to 100 per inch, a quartz lens for focusing the source, a source aligning device, and a spark stand with adjustments for centering the source. The log sector disk was placed as close to the slit of the spectrograph as possible, the distance separating them being 1.5 cm. The quartz focusing lens was placed 2 cm. from the sector and the electrode holders adjusted so as to throw an image of the source on the collimating lens of the spectrograph. In the present case this required a distance of 25 cm. from the focusing lens to the electrodes.

The sector was of rather unconventional design, the log curve being reversed from the usual position, as shown in Fig. 1. This places the smallest openings of the sector at a greater distance from the center of the disk, and the disk can be cut more accurately since the circumferential distances are greater. The maximum sector opening of 180 deg. is only half that of the conventional sector. This makes it necessary to double the length of exposure. This is not a serious drawback, however, since the exposures are not long.

Excitation:

Arc excitation in graphite electrodes was tried but proved unsatisfactory owing, undoubtedly, to factors which could be overcome. It was found that $SnCl_4$ and $BiCl_3$ were lost from the electrodes due to volatilization while drying, and that the high background densities encountered due to impurities in the graphite and cyanogen bands in the longer wave lengths caused a loss in sensitivity. Also analysis for low concentrations of bismuth was found to be impractical by the log wedge sector method, since a weak tin arc line at 3067.8 Å is too close to the persistent bismuth line at 3067.73 Å for accurate measurements to be made visually.

The spark technique eliminates these difficulties and was found to give sufficient sensitivity for analyzing commercially pure tin.

The electrical apparatus consisted of a transformer connected through a variable resistance to a 220-v. 60-cycle power line. The maximum voltage at the secondary was 23,000 v. All of the work presented here was done with the variable resistance adjusted to give 15,000 v. A capacitance of 0.002 μf. was used in parallel and a self inductance of 0.012 mh. in series with the secondary. The current through the primary of the transformer was 1.50 amp. These values were maintained throughout the work.

It was found that this technique gave a very steady spark which showed no tendency to spark preferentially to the grain boundaries or to any constituents of the electrodes. Also, no difficulty from the formation of tin oxide was experienced under these conditions. Hitchen[6] experimented with various spark excitations and found that conditions very similar to those used in this case gave the most satisfactory results.

Standard Alloys:

All of the standard alloys were prepared by making up master alloys and diluting to give the various concentrations desired. Chempur tin and oxygen-free high-conductivity copper, special high-purity Cerro de Pasco bismuth, hydrogen-purified carbonyl iron, commercial soft lead, and Baker's c.p. antimony were used in making the master alloys.

The bismuth, lead, and antimony alloys were melted in Pyrex glass beakers under paraffin and solidified quickly by playing a cool air blast on the outside of the beaker. The copper alloy was treated in the same manner except that a flux of 70 per cent zinc chloride and 30 per cent ammonium chloride was used in place of paraffin. This method of casting was found to give very homogeneous alloys. The iron alloy was melted in a clay crucible under a cover of calcium oxide and cast in a narrow iron trough to secure fast freezing. Even with this treatment the ends of the casting were low in iron.

Chemical analyses were made on all master alloys to find the actual alloy content and to detect any inhomogeneity which might affect the composition of the standard alloys. Three samples were taken from each master alloy, one from the center of the casting and two near the edge. The results are given in Table I.

TABLE I.

	Copper, per cent[a]	Bismuth, per cent[b]	Iron, per cent[c]	Lead, per cent[d]	Antimony, per cent[e]
End	4.24	4.84	2.62	5.00	4.63
Center	4.34	4.86	2.68	5.01	4.59
End	4.24	4.87	2.52	4.96	4.59

[a] W. W. Scott, "Standard Methods of Chemical Analysis," Third Edition, Vol. 1, pp. 184–185 (Sulfide separation, electrolytic deposition).

[b] W. W. Scott, *Ibid.*, p. 71.

[c] A. E. Leighton, "Standard Method for the Analysis of Pure Tin," Australia Department of Defense Munitions Supply Board, May 1936.

[d] W. W. Scott, *Ibid.*, p. 271.

[e] W. W. Scott, *Ibid.*, p. 26.

The various concentrations for making working curves were made up by adding weighed amounts of the master alloys to high-purity tin. Special high-purity tin made by the Vulcan Detinning Co. was used for the lower concentrations of copper and bismuth, while Chempur tin was used for all other alloys.

These alloys were cast in Pyrex tubes of 5-mm. inside diameter under a cover of paraffin. This glass tube was joined at the open end to a Pyrex tube of larger diameter and sealed at the other end so that the molten metal could be poured back and forth to facilitate thorough mixing of the constituents. Care was taken not to heat the bismuth and antimony alloys higher than necessary to guard against loss of these volatile elements. The alloys were frozen quickly in the 5-mm. glass tubing with the aid of a cool air blast to prevent segregation.

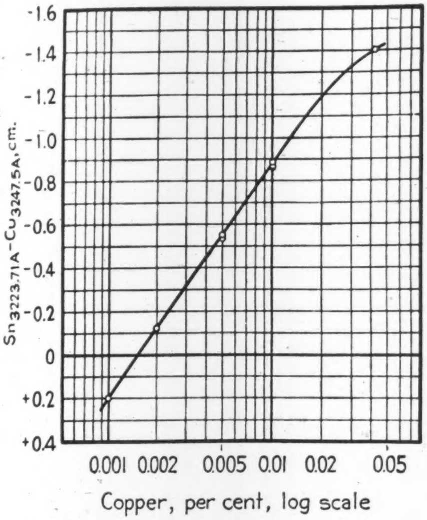

FIG. 2.—Working Curve for Copper in Tin, Using the Line Pair Tin 3223.71 Å and Copper 3247.5 Å.

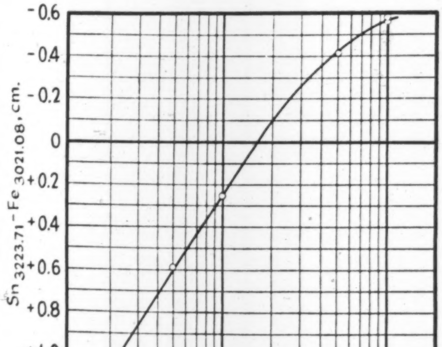

FIG. 4.—Working Curve for Iron in Tin, Using the Line Pair Tin 3223.71 Å and Iron 3021.08 Å.

Electrodes:

The standard alloys cast in this manner were cut in half and the ends which had been in the center were filed to chisel points of about 60 deg. The pointed edges were filed down to give sparking surfaces of 5 by 1 mm.

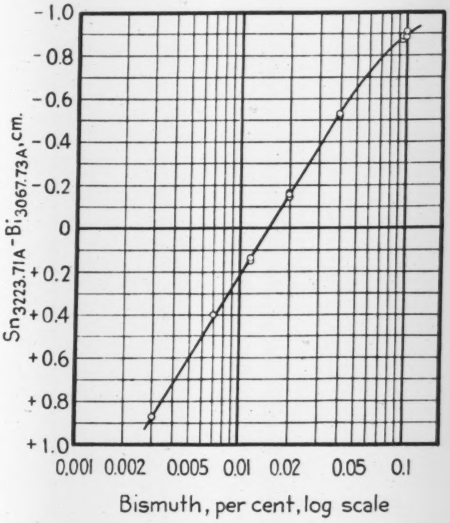

FIG. 3.—Working Curve for Bismuth in Tin, Using the Line Pair Tin 3223.7 Å and Bismuth 3067.73 Å.

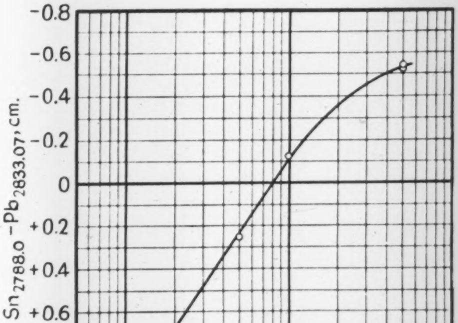

FIG. 5.—Working Curve for Lead in Tin, Using the Line Pair Tin 2788.0 Å and Lead 2833.07 Å.

These electrodes were mounted in the spark stand with a distance between them of 4 mm. After centering, the electrodes were sparked for three minutes with a spectrograph slit width of 0.04 mm. Eastman 40 plates were used and were developed 3 min. in Eastman D-11 developer.

Working Curves:

To secure a null method with respect to slight changes in excitation conditions, exposure, and development, the internal standard method was used. The intensity of a spectral line of the element in question was compared with the intensity of a tin line by measuring the length of their traces on the photographic plate. The lines employed were chosen for their proximity to one another, their similarity of excitation, their similarity of appearance (well defined or diffuse), and their intensity at the concentrations used. In the case of copper, bismuth, and lead, pairs of lines recommended by Smith[2] were used. It was found that the antimony line at 2598.08 Å was more persistent under the excitation conditions used than the antimony line at 2528.5 Å.

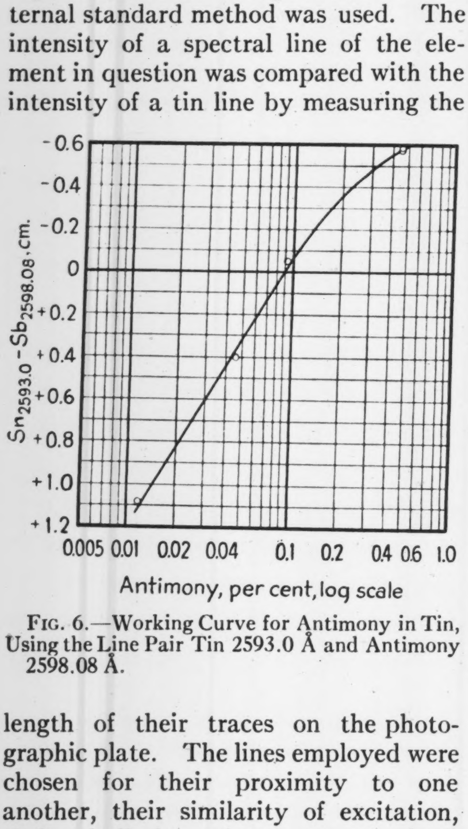

FIG. 6.—Working Curve for Antimony in Tin, Using the Line Pair Tin 2593.0 Å and Antimony 2598.08 Å.

The lengths of the lines were measured on an accurate comparator using a 6 × magnifier, the spectrograms being illuminated with diffuse light from the back. Experience indicates that the error of reading is less than 0.2 mm.

The working curves obtained by this procedure are plotted in Figs. 2 to 6 by the use of what is really a log-log plot, since the logarithmic sector disk gives a logarithmic significance to the lengths of the spectral lines. Such a plot of the log intensity *versus* the log concentration gives a straight line except at the higher concentrations where self reversal becomes appreciable and causes a decrease in the slope of the curve. The flatness of the curve in the higher concentrations decreases the accuracy of the method, since the error in measuring line lengths produces a larger error in the analysis than it would on a portion of the curve which is steeper.

The lower limit of the method is reached only when the concentration of the element is so low that it gives no line on the photographic plate.

In making the working curves, several alloys of the highest concentration used were made up for checking purposes. The maximum variations are shown by the two points recorded in each of these curves. The copper and bismuth curves were further checked at lower concentrations, and the points showed very good agreement. It was decided, therefore, that it was unnecessary to check further the points corresponding to lower concentrations of iron, lead, and antimony, since they lie on the linear portions of the curves and thus check one another.

The working curves are used in the analysis of the material whose composition is sought. Measurements are made of the lengths of the line pair used in making the working curve for the element in question. The difference in the lengths of the two lines is then translated into percentage composition of element with the aid of the working curve.

Summary and Conclusions:

After an examination of both the arc and spark methods, it has been found that the spark method holds advantages over the arc method for quantitative analysis of tin by the log wedge sector method with respect to ease of use, rapidity, uniformity of results, and, in the case of analysis for bismuth, sensitivity.

Working curves have been set up for the quantitative analysis of copper in tin covering a range from 0.001 per cent to 0.05 per cent, bismuth in tin from 0.003 per cent to 0.10 per cent, iron in tin from 0.002 per cent to 0.10 per cent, lead in tin from 0.01 per cent to 0.50 per cent, and antimony in tin from 0.01 per cent to 0.50 per cent.

It is hoped that the work presented in this paper will be of assistance to those interested in a quick convenient method for the analysis of commercial grades of tin for their major impurities with a minimum of costly and cumbersome equipment.

Acknowledgments:

The author is indebted to Gerhard Derge for assistance in planning this work. The Bristol-Myers Co. of New York City has sponsored the research program of which this investigation is a part.

DISCUSSION

Mr. T. A. Wright.[1]—I find Mr. Stewart's experience with the log sector interesting. Ours was somewhat discouraging, not on tin but in general on the use of the logarithmic sector, because we found it almost impossible to get the assurance we should have in regard to the length of our wedge. I am wondering just how Mr. Stewart gets that assurance in general. What would be an average error in line measurement? In the range of 0.2 mm.?

I should like to ask further why the method was not tried for silver and nickel, which are in general run on refined tin, and why not for cobalt and zinc, which are sometimes, but rarely, run. Did the author find, as we did, some time ago—that indium is often a component of tin?

Silver will be found in all of them, as far as I know. We have no difficulties whatever with the arc solid method in obtaining bismuth in the fourth decimal place.

Mr. J. Warren Stewart[2] (*author's closure*).—I am very glad to have this discussion by Mr. Wright, since I know he has had a great deal of experience with spectrographic analysis and since he has brought up some important and interesting points. I think that the arc excitation is not so good for tin analysis because it is difficult to read the bismuth line at 3067.716 Å, since it is masked by a weak tin arc line at 3067.755 Å; however, I imagine that if one used an instrument of higher dispersion it might be possible to separate these two lines sufficiently.

As to the satisfactory nature of the log wedge sector, we had a great deal of trouble reading line lengths at first. It often appears that the end of a line is reached, but a little farther on there are seen clusters of silver grains which make it difficult to decide on the true line length. However, after experience has been gained, quite satisfactory results are obtained. The value 0.2 mm., which Mr. Wright mentioned, was the maximum error in reading the length of the spectral lines. This error was the same no matter how long the line was. Mr. Wright's experience with regard to silver, nickel, cobalt, and zinc in tin differs somewhat from ours. However, it must be remembered that our work was on the brands of tin of the highest commercial purity. The purity of these brands is reported in the literature as follows: Banka, 99.983 per cent tin; Straits Trading, 99.844 per cent tin; E. S. Coy, 99.892 per cent tin; and Tulip Refined, 99.870 per cent tin.[3] Lately we have tested tin in which we found silver, and have started work on analyzing for it in tin. In regard to the reference to indium, we have noted traces of it in several brands of tin.

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[1] Technical Director and Secretary, Lucius Pitkin, Inc., New York City.

[2] Metals Research Laboratory, Carnegie Institute of Technology, Pittsburgh, Pa.

[3] Statistical Year Book, Internat. Tin Research and Development Council (1937)

SPECIFIC SURFACE AND PARTICLE SIZE DISTRIBUTION OF FINELY DIVIDED MATERIALS

By M. N. States[1]

Synopsis

General equations are given for specific surface and particle size distribution of finely divided materials. Through the use of these equations the Wagner method may be applied to fineness studies in which various particle size ranges are used. Corresponding expressions for the portland cement schedule may be derived from the general relationships. Analysis of the fundamental principles of the Wagner method, the working equations and various sources of experimental error indicate that the accepted experimental technique may be considerably simplified. An instrument and accessories are described which lend themselves to the use of the simplified procedure for fineness measurements. Data are shown, using portland-cement samples prepared by the National Bureau of Standards, which are illustrative of the technique and which support the theoretical conclusions.

A number of optical methods have been described for the measurement of particle-size distribution and specific surface of finely divided materials. Perhaps the most widely used procedure is that devised by Wagner[2] for portland cement. In this method the particles are dispersed in a suitable liquid medium and, as the particles settle, observations are made on the varying transmission factor of the suspension at a reference level below the surface of the liquid. It is assumed that the particles obey Stokes' law of fall. Accordingly, of the various sizes of particles originally at the surface of the suspension, the larger pass the reference level sooner than do the smaller. At a particular instant when all particles larger than $d\mu$ have passed the reference level, it is assumed that the surface area of all particles of size less than $d\mu$ is proportional to the instantaneous value of the negative logarithm of the transmission factor. Through use of these two basic assumptions, expressions may be derived for the specific surface and particle distribution which lend themselves to measurement.

Stokes' law may be written in a suitably modified form

$$t = \frac{18\,h\,u \times 10^8}{(P_1 - P_2)g\,d^2} \dots\dots (1)$$

where t is the time in seconds required for particles having diameters $d\mu$ to settle a distance h cm. in a medium whose density and viscosity are respectively P_2 g. per cu. cm. and u poises. P_1 is the density of the dispersed particles in grams per cubic centimeter and g is the acceleration of gravity in centimeters per second per second. The transmittancy relation is

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[1] Director of Research and Development, Central Scientific Co., Chicago, Ill.

[2] L. A. Wagner, "A Rapid Method for the Determination of the Specific Surface of Portland Cement," *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 553 (1933).

$$\begin{aligned} S_d &= -c \log (I_d/I_0) \\ &= c (\log I_0 - \log I_d) \quad \text{......} (2)^3 \end{aligned}$$

where S_d is the surface area in square centimeters of all particles smaller than $d\mu$, c is the proportionality factor, assumed constant for all concentrations whose transmissions lie within a moderately limited range near unity and for all particle sizes. I_0 is the intensity of the light transmitted by the dispersing medium when no particles are present and I_d is the instantaneous value of the transmitted light intensity at the time all particles greater than $d\mu$ have settled below the reference level. Since it is the usual practice to measure the light intensities by means of a self-generating type of photocell which is operated under such conditions that its current response is directly proportional to the light intensity, the quantities I_0, I_d, etc., are measured in microamperes, or in arbitrary units of a uniformly scaled instrument having 100 divisions.

TABLE I.—COMPARISON OF RESOLVING POWER OF THE PHOTELOMETER AND WAGNER TURBIDIMETER.

Particle Size	Photelometer $a = 0.1$ cm.		Wagner Turbidimeter, $a = 1.27$ cm.	
$d\mu$	h, cm.	R	h, cm.	R
60	3.1	1.03	15.0	0.394
30	3.1	2.07	15.0	0.788
25	3.1	2.48	13.1	0.827
7.5.....	3.1	8.27	2.1	0.44

SPECIFIC SURFACE AND PARTICLE SIZE

The specific surface S is defined as the surface area of all particles of size less than $d_m\,\mu$ per gram of entire sample. A procedure based on the assumptions previously mentioned and explicitly stated in Eqs. 1 and 2, and similar to that described by Wagner, leads to the general expression for specific surface,

$$S = \frac{1200\,r}{P_1} \cdot \frac{(\log I_0 - \log I_m)}{[\sum d \log I]} \quad ..(3)$$

where the bracketed summation is an abbreviation of the general expression

$$[\sum d \log I] = \left[\left\{ \sum_{z=0}^{z=m} (d_{z+1} - d_{z-1}) \log I_z \right\} - d_m \log I_m \right]. \quad (4)$$

in which d_{-1}, d_0 and d_{m+1} are arbitrarily set equal to zero.

In addition to the quantities previously defined, $I_1, I_2, \ldots I_m$ are the instantaneous values of the transmitted light energy at instants when all particles greater than $d_1, d_2, \ldots d_m\mu$ have settled below the reference level, and r is the weight percentage of the entire sample comprising particle sizes less than $d_m\,\mu$.

For the portland cement schedule in which $d_1, d_2, d_3, \ldots d_m$ correspond to 7.5, 10, 15, ... 60 μ, Eq. 3 reduces to[4]

$$S = \frac{1200\,r}{P_1} \cdot \frac{(2 - \log I_{60})}{10(1.5 + \log I_{7.5} + 0.75 \log I_{10} + \log I_{15} + \cdots + \log I_{55} - 11.5 \log I_{60})} \quad . (5)$$

One may also derive a general expression for particle size distribution, the

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[3] Base 10 logarithms are used in this analysis.

[4] In deriving the expression corresponding to Eq. 5, Wagner apparently assumed the average particles within the range 7.5 to 10 μ to be 7.5 μ instead of 8.75 μ. In consequence his expression for specific surface differs from Eq. 5 by a transposition of the coefficients of $\log I_{7.5}$ and $\log I_{10}$. Since the Wagner expression for specific surface has been widely adopted for portland cement, the Wagner equation is used in this study. For studies on other finely divided materials, the expansion of Eq. 3 is to be preferred.

weight percentage of the entire sample Y_x, having diameters less than d_x μ.

$$Y_x = \frac{r}{[\sum d \log I]} \cdot \left[\left\{\sum_{z=0}^{z=x} (d_{z+1} - d_{z-1}) \log I_z\right\} - d_x \log I_x\right]. \quad (6)$$

in which d_{-1}, d_0 and d_{x+1} are arbitrarily set equal to zero. This equation is valid for the determination of a series of weight percentages for the selected particle sizes of a particular test. The usual portland cement weight percentage may be determined by the repeated expansions of Eq. 6. However, in the expansion, the average particle size is assumed to be the average size within the range; that is, for the portland cement schedule the average size in the range 7.5 μ to 10 μ is taken as 8.75 μ instead of 7.5 μ as apparently assumed by Wagner. Weight percentages in Table II were computed by means of Eq. 6 which was modified to conform to the Wagner assumption.

TABLE II.—SPECIFIC SURFACE AND PARTICLE DISTRIBUTION TESTS.

Sample, N.B.S. No. 114a. Percentage passing No. 325 sieve, r, 88.7.
Density, P_1, 3.15 g. per cu. cm. Temperature of suspension, 71 F.
Date, April 13, 1937. Viscosity, dispersing medium, 0.0175 poises.
Density, dispersing medium, 0.79 g. per cu. cm.
Depth of suspension to reference slit, h, 3.10 cm.
Y_x = Weight percentage of all particles less than $d\mu$ in diameter.
$Y_x(a)$ = Average weight percentage of five tests.

$d\mu$	Time, sec.	Test No. 1			Test No. 2			
		I_d	$\log I_d$	Y_x	I_d	$\log I_d$	Y_x	$Y_x(a)$
60	11.7	35.7	(1.5000)[a]	88.7	21.8	(1.5000)[a]	88.7	88.7
55	14.0	35.8	1.5539	87.2	21.9	1.3404	86.9	87.1
50	16.8	36.0	1.5563	84.5	22.0	1.3424	85.4	84.7
45	20.8	36.4	1.5611	79.4	22.2	1.3464	82.5	80.0
40	26.4	36.9	1.5670	73.6	22.5	1.3522	78.7	74.9
35	34.4	37.1	1.5694	71.6	22.9	1.3598	74.4	72.0
30	46.8	37.7	1.5763	66.6	23.3	1.3674	70.6	67.3
25	67.6	38.7	1.5877	59.6	24.4	1.3874	62.3	60.9
20	105	39.9	1.6010	53.0	26.0	1.4150	53 0	52.4
15	187	42.2	1.6253	43.5	29.1	1.4639	40.0	40.9
10	422	47.4	1.6758	29.3	32.8	1.5159	30.2	28.8
7.5	750	50.3	(1.2762)[b]	25.0	36.6	(1.1726)[b]	24.8	24.8

Test No. 1:

Total = 18.6500
$11.5 \log I_{60}$ = 17.8560
$1/10\,[\Sigma d \log I]^c$ = 0.7940

$\log I_{7.5}$ = 1.7016
$\log I_{60}$ = 1.5527
$2 - \log I_{60}$ = 0.4473

$$S = \frac{120 \times 88.7 \times 0.4473}{3.15 \times 0.7940} = 1906 \text{ sq. cm. per g.}$$

Test No. 2:

Total = 16.5634
$11.5 \log I_{60}$ = 15.3927
$1/10\,[\Sigma d \log I]^c$ = 1.1707

$\log I_{7.5}$ = 1.5635
$\log I_{60}$ = 1.3385
$2 - \log I_{60}$ = 0.6615

$$S = \frac{120 \times 88.7 \times 0.6615}{3.15 \times 1.1707} = 1912 \text{ sq. cm. per g.}$$

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[a] 0.75 log 100.
[b] 0.75 log $I_{7.5}$.
[c] Summation Eq. 4 changed to conform to the Wagner expression for S.

RESOLVING POWER

On the assumption that the particles are completely dispersed, at zero time, the transmission factor of the suspension, at the reference slit, is produced by the combined effect of the particles of all sizes present in the suspension. At various subsequent instants all particles larger than $d\mu$, in accordance with Eq. 1, have passed the reference level, and the light transmission results from absorption and scattering by particles smaller than d μ. Since the slit has a finite width and since particles of larger size reach the reference level before those of smaller size, a uniform distribution of particles of size less than $d\mu$ does not occur within the area of the slit. In fact, a particle size gradient, with respect to vertical slit width, obtains for a range of particles having limiting diameters defined by Eq. 1 for the top and bottom of the slit. This suggests that the slit width may have a definite bearing on the accuracy of results obtainable with a particular instrument, and that a narrow slit may be desirable.

By Eq. 1 we may determine, at any instant, a particle size d_1 defining a boundary level h_1, above which all particles are smaller than $d_1\mu$. Likewise we may determine a level h_2 above which all particles are smaller than $d_2\mu$. (Fig. 1.) As explained above, a particle size gradient, $\Delta d/\Delta h$, occurs between these boundaries, where $\Delta d = (d_2 - d_1)$ and $\Delta h = (h_2 - h_1)$. For the transmittancy relation, Eq. 2, to be precisely valid, either this gradient or the slit width would have to be zero. In actual practice neither of the conditions is fulfilled. A measure of the extent of this non-uniform distribution is the particle size gradient times the slit width. By analogy with resolving power in optics, the reciprocal of this quantity may be defined as the resolving power:

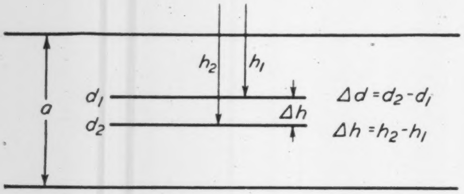

FIG. 1.—Vertical Cross-section of Slit a.

$$R = \frac{1}{a(\Delta d/\Delta h)} \quad \ldots\ldots\ldots (7)$$

In view of Eq. (1),

$$R = (2h)/(ad) \quad \ldots\ldots\ldots (8)$$

From Eq. 8 the resolving power of the instrument is not only a function of the height of fall h and slit width a, but also the particle size d. A comparison of the resolving power of the Photelometer and the Wagner turbidimeter is shown in Table I for several particle sizes. Computations for resolving power are based on the use of both instruments in the measurement of specific surface of portland cement. The Photelometer is seen to have the larger resolving power for all particle sizes.

PRECISION OF MEASUREMENT

It is generally recognized that the fundamental assumptions underlying Eq. 5 may be quite at variance with actual physical conditions. For example, the particles are certainly not spherical and, in settling, probably deviate from Stokes' law. Furthermore, the transmittancy relation, Eq. 2, is probably valid only within a limited range of transmission factors near unity. To the extent that the assumptions are not realized, or that deviations from assumptions are non-compensating, the experimental value of specific surface is in error. In the case of portland cement surface areas determined by the Wagner procedure may be greatly in error. Gran[5] points out, "One often finds results of specific surface recorded to the nearest square centimeter per gram, when in actuality the nearest hundred square centimeters represents a degree of accuracy that is unobtainable." However, this situation does not vitiate the value of the measurements since absolute values of specific surface are, in many instances, not significant. So long as precise relative measurements may be made and checks obtained among various laboratories and on different instruments, the value of the tests is unimpaired.

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[5] J. R. Gran, "Some Suggested Practices in the Estimation of Particle Size Gradation of Granular Materials," ASTM BULLETIN No. 88, October, 1937, p. 19.

Aside from these inherent fundamental discrepancies in the Wagner procedure, it is worth while to examine Eq. 5 for significant experimental errors. The value of S as determined by this expression, on either the Photelometer or the Wagner turbidimeter, depends upon several observations, each of which is susceptible of error. The influence of each of these errors on the value of S may be determined by taking the partial derivative of S, in Eq. 5, with respect to each of the observations, $I_{7.5}$, I_{10}, $I_{15} \ldots I_{55}$, I_{60}. The total error in S is the sum of the individual errors. Consequently,

$$\frac{\sum \Delta S}{S} = \frac{0.434\,S}{G\log(100/I_{60})} \left[\frac{\Delta I_{60}}{I_{60}}(11.5 - G/S) - \left(\frac{\Delta I_{55}}{I_{55}} + \frac{\Delta I_{50}}{I_{50}} + \cdots + \frac{\Delta I_{10}}{I_{10}} + 0.75\,\frac{\Delta I_{7.5}}{I_{7.5}}\right)\right]. \quad (9)$$

where, in addition to quantities already defined, $\Sigma\Delta S/S$ is the fractional error in the specific surface arising from various fractional errors in the instrument observations, and $G = 120\ r/P_1$. For the National Bureau of Standards' sample 114*b*, for which $S = 1910$, $r = 88.9$ and $P_1 = 3.15$, Eq. 9 reduces to

$$\frac{\sum \Delta S}{S} = \frac{0.245}{\log(100/I_{60})} \left[9.73\,\frac{\Delta I_{60}}{I_{60}} - \left(\frac{\Delta I_{55}}{I_{55}} + \frac{\Delta I_{50}}{I_{50}} + \cdots + \frac{\Delta I_{10}}{I_{10}} + 0.75\,\frac{\Delta I_{7.5}}{I_{7.5}}\right)\right]. \quad (10)$$

For a ±0.1 division error in I_{60}, the value I_{60} ranging from 15 to 30 divisions, the error in the specific surface varies from ±1.9 to ±1.5 per cent. Although the microammeter may be read to 0.1 division, deviations from uniform calibration at a given portion of the scale, as well as errors arising from observing a moving needle and making the reading without parallax, suggest 2 per cent as the lower limit of error in specific surface from this cause alone, by the most skilled operator. Obviously, error in specific surface contributed by any of the other observations is negative and about one-tenth as great. It can be shown that the minimum error in specific surface occurs when I_{60} is 36.8 divisions. In general, therefore, suspension concentrations should be adjusted so that the initial reading is about 30 divisions.

While it may be unfortunate that errors in I_{60} have such a marked influence on the value of the specific surface, a careful examination of Eqs. 9 and 10 reveals fortunate compensations. In the Photelometer technique to be described later it has been found possible to take advantage of these. For portland cement, twelve observations are made: I_{60} to $I_{7.5}$. Beginning with I_{60} each observation is larger than the preceding. Consequently, the fractional errors $\Delta I_{60}/I_{60}$, $\Delta I_{55}/I_{55}$, $\ldots\ \Delta I_{7.5}/I_{7.5}$ are successively smaller for equal errors in individual observations, and, under such circumstance, the eleven negative contributions to error in specific surface largely offset the error introduced by the I_{60} term. Hence errors in technique or in the instrument which produce either equal positive or equal negative errors in the microammeter indications may be tolerated.

Perhaps the most obvious and the most striking illustration of the type of instrument error which has no appreciable effect is an incorrect zero setting of the microammeter. Such an error increases or decreases each of the observations by the same amount, and the positive and negative errors cancel. For example, if *one division* is added to each of the readings in the first set of data of Table II, the change in specific surface is less than 5 parts in 2000. On the other hand if I_{60} is changed by only 0.1 division, the other readings remaining the same, the variation in specific surface is about 2 per cent.

If the I_0 setting is not exactly 100, but if the standard setting remains constant during the run, precise values for the specific surface may be obtained. The compensating effect is perhaps not so striking or so complete as in the first illustration, but the Photelometer yields acceptable values when I_0 is 100 ± 3 divisions.

It is difficult to believe that the method prescribed in A.S.T.M. Tentative Method of Test for Fineness of Portland Cement by means of the turbidimeter (C 115 - 38 T)[6] for setting the Wagner turbidimeter to the standard setting, $I_0 = 100$, is precise. Assuming the original setting to be correct, it is too much to expect the setting to hold from day to day throughout the life of the light bulb. It is conceivable that the success of this procedure may be attributed to a compensation of errors. In the opinion of the author, the use of a standard sample in securing a standard setting is entirely unnecessary.

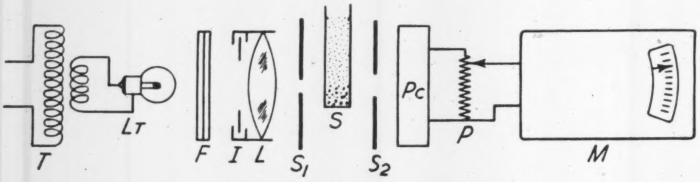

FIG. 2.—Schematic Diagram of the Photelometer Arranged for Fineness Measurements.

Unavoidable small differences in the height of fall h in successive runs without corresponding changes in time schedule is an example of a source of error which is self-compensating. Attention is called to Table IV. In these representative tests the height of fall was deliberately changed by 12 per cent without significant variation in specific surface. To effect this change in h, kerosine was added to the original sample. Therefore, all of the data shown were taken with a single set of particles, the sample being redispersed three times in the first test, twice in tests 2 and 3.

Perhaps the most significant prediction of Eq. 10, which greatly simplifies the technique described by Wagner, is that moderate differences in temperature of the suspension at which different runs are made are unimportant. From Eq. 1 the times for making readings are directly proportional to the viscosity u. This quantity is a function of the temperature, but changes in viscosity produce the same effect on the calculated specific surface as changes in the height of fall. Consequently, considerable change in the viscosity, and therefore the temperature of the suspension, may be tolerated, and the use of a timing burette eliminated in favor of the more precise signalling clock.

Automatic temperature compensation is not so complete when changes in temperature take place in the suspension during a run. Such changes in temperature are to be avoided, especially if the time for making the initial reading is in excess of a few seconds. The correction does not apply for eddy currents produced by temperature conditions as described by Ponzer and MacPherson.[7] However, the dimensions of the absorption cell used in the Photelometer and the practice of using a long narrow slit of light reduce eddy current effect to the minimum.

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[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 746 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 483.

THE PHOTELOMETER

A schematic diagram of the Photelometer, as arranged for measurement of specific surface and particle size distribution, is shown in Fig. 2. Light from the source *Lt* passes through the heat absorber *F*, the iris diaphragm *I*, the lens *L*, the reference slit S_1, the suspension *S*, and the shielding slit S_2 to the photocell *Pc*. The slit S_1 has a vertical width of 0.1 cm.; the slit S_2, which is parallel to S_1, has a width of about 0.3 cm. The output of the self-generating type of photocell is connected through a potential divider to a microammeter having a uniformly calibrated scale of 100 divisions. The resistance of the potential divider is such as to slightly underdamp the instrument, which deflects full scale for about 15 microamperes.

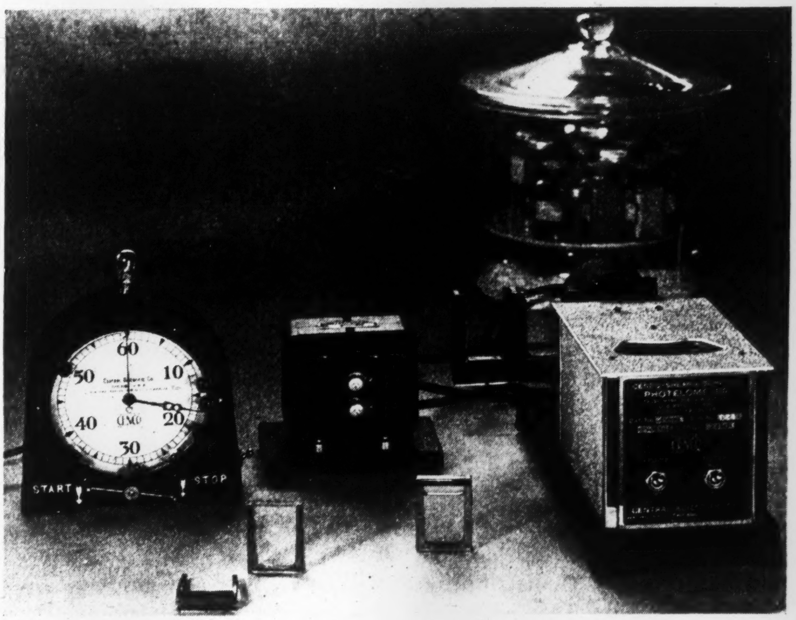

FIG. 3.—Photelometer and Accessories Arranged for Fineness Measurements.

The absorption cell is about 3 cm. wide, 5 cm. high, and 1 ± 0.005 cm. in depth. The maximum amount of liquid suspension which may be used in the cell is about 15 ml. When this cell is in the light path the bottom of the cell is about 0.5 cm. below the reference slit and the maximum height through which the particles may fall is about 3.5 cm. For portland cement the value of *h* has usually been adjusted to 3.4 cm., requiring 13 ml. of kerosine. For extremely fine powders having a density of 16 g. per ml. the height of fall is about 2 cm. In use the cell is closed with a leak-proof cover, held in place by means of metal clips.

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[7] H. S. Ponzer and D. R. MacPherson, "Studies of the Operation of the Wagner Turbidimeter," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 441 (1938).

The light is a special 6 v. 50 c.p. incandescent bulb energized preferably by a constant wattage transformer T operated from a constant-frequency power line. The light circuit is constructed to maintain a constant circuit resistance.

The iris diaphragm and the potential divider, when properly manipulated, produce an I_0 setting equal to 100 with the maximum horizontal slit length. The relatively long slit length with respect to the slit width (about 20 to 1) assures a precise average transmission factor for the settling particles as they pass the reference level.

Readings are made at instants indicated by a signalling clock which is powered by a synchronous motor and which is operated from a controlled frequency power line. During the first minute, when the interval between readings is a matter of seconds, signals are flashed to the operator by a small light. Seven contacts on the clock dial may be set for any time schedule within the first minute. After the first minute, the operator observes the second hand in following the time schedule.

The Photelometer and accessory apparatus required for making specific surface and particle size distribution measurements are shown in Fig. 3. The various items are: the Photelometer, the constant wattage transformer, the observation cells (1 covered, 1 with cover removed), and the signalling clock. The carriage, by means of which the absorption cell containing the suspension is moved into the light path, is shown extending to the left. An absorption cell containing clear kerosine is in the central compartment of the carriage.

TECHNIQUE

To determine the specific surface and particle size distribution of a powder, one must first secure a suitable liquid dispersing medium. The liquid will depend upon the kind of particles to be dispersed and such factors as density and size of particles. Water clear kerosine, with a small quantity of oleic acid which acts as a dispersing agent, has been found generally useful. However, in studies on tooth powders, abrasive powders, tungsten and tantalum carbide powders, water and methyl alcohol have been used.

With the exception of portland cement, for which the particle size ranges are established, a suitable particle size range and corresponding time schedule must be determined before precise measurements can be made. The following procedure has been found practicable. First disperse the powder, as described later, in the liquid medium and plot a curve of meter readings against time. The observations should be made soon enough after the particles have been dispersed so that the first indications of the meter are identical. In this way one can determine approximately when the last of the largest particles reach the reference slit and by means of Eq. 1 calculate their size. If the size determined is, say, 20 μ, a time schedule should be established with an upper size limit of 25 or 30 μ so that one may reasonably assume that $r = 100$. It may be shown that the use of transmission factors corresponding to particle sizes greater than those present in the suspension automatically cancel and have no influence upon the computed value of either the specific surface or of particle size distribution.

After the upper particle size limit has been determined, a preliminary time schedule should be established corresponding to 8 or 10 particle sizes within the required range. The difference between sizes may be from 1 to 5 μ. For simplicity in calculation they should be equally spaced. With such a schedule a set of readings may be taken and a particle size distribution computed. If more than 25 per cent of the particles are below the smallest size included within the preliminary schedule ($V_1 > 25$ per cent), the final schedule should be modified to include smaller particles. This is of extreme importance since, as suggested by Roller,[8] the upper limiting value for specific surface for any time schedule is $12 \times 10^4/P_1d_1$ sq. cm. per g. In making such adjustment the height of fall may be changed to secure a reasonable time schedule. When the various constants are properly chosen, the time schedule will probably not exceed 15 min.

After the time schedule has been determined, observations may be taken and computations made using Eqs. 3 and 6, which have been expanded to correspond to the particle size schedule selected.

In the following studies, National Bureau of Standards samples of portland cement were used to test the reliability of the Photelometer in the measurement of specific surface and particle size distribution and to investigate some of the implications of Eqs. 5 and 10. With the exception of Tables II and III, the data more specifically concern the latter problem rather than illustrate precision in measurement. Numerous tests, using a greatly simplified technique over that prescribed in the A.S.T.M. method C 115, have demonstrated that the Photelometer may be used successfully in fineness measurements. The precision of the measurements is in good agreement with that predicted by Eq. 10. Tables II and III are representative samples of data.

Prior to making measurements, the instrument must be adjusted to the standard setting $I_0 = 100$. The iris diaphragm, which fixes the amount of light passing through the suspension by varying the length of slit S_1, is first opened to the 2.0 cm. mark. The potential divider is then set to produce a meter indication of about 100 divisions. Final adjustment to the 100 setting is made with the iris diaphragm, the final slit length (S_1) being about 2.0 cm. During this adjustment, an absorption cell having exactly the same thickness as the one in which the suspension is placed and containing water clear kerosine, is in the light path. In order that the photocell may reach a stable condition and to prevent variation in I_0 during a test, it is advisable to allow the instrument to stand, after making the above setting, for about 20 or 30 min. preceding the first daily run. Between trials, the light is left on with the clear

TABLE III.—TESTS ON NATIONAL BUREAU OF STANDARDS SAMPLE 114 b.

Test	I_{60}	S, sq. cm. per g.	Deviation from Mean, sq. cm. per g.
No. 1.......	31.0	1897	−10
	33.8	1950	+43
No. 2.......	31.6	1940	+33
	34.1	1940	+33
	31.2	1922	+15
	31.0	1940	+33
No. 3.......	38.2	1870	−37
No. 4.......	32.2	1918	+11
	32.0	1953	+46
No. 5.......	37.2	1920	+13
	37.0	1905	−2
	34.0	1918	+11
No. 6.......	32.7	1877	−30
	30.9	1910	+3
	27.9	1865	−42
No. 7.......	44.1	1850	−57
	42.2	1850	−57
Mean.............		1907	Avg...28

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[8] Discussion by P. S. Roller of paper by Ponzer and MacPherson, "Studies of the Operation of the Wagner Turbidimeter," *Ibid.*, p. 458.

kerosine in the light path. Final setting of $I_0 = 100$ for any test is made just before moving the suspension into the light path.

TABLE IV.—SPECIFIC SURFACE VERSUS HEIGHT OF FALL (N.B.S. NO. 114 b).

Test	h, cm.	I_{60}	S, sq. cm. per g.
No. 1........	3.2	32.1	1880
	3.2	32.2	1920
	3.2	30.8	1950
No. 2........	3.4	34.1	1940
	3.4	32.0	1954
No. 3........	3.6	36.7	1972
	3.6	37.1	1920
Mean........................			1934

The suspensions are made by placing a small amount of cement in the absorption cell which contains a measured quantity of kerosine. Although an unweighed sample is used, the operator quickly acquires the ability to judge the required amount to produce an initial reading (I_{60}) between 30 and 40 divisions. In most of the measurements of this study, about 0.05 g. of cement and 13 ml. of kerosine were used. A drop of oleic acid is placed in the cell, the cell is covered and vigorously shaken for about one minute. At the instant the suspension is placed in the carriage, the signalling clock is started. The cell is quickly moved into position and observations $I_{60}, I_{55}, \ldots, I_{7.5}$ are made according to the predetermined schedule.

Table II illustrates measurements made on National Bureau of Standards sample No. 114 a. The value of r and density P_1, as indicated by the Bureau, were used in the computations. The specific surface of the sample, as given by the Bureau, is 1900 sq. cm. per g. Particle size distributions are shown for the two individual runs, and on the extreme right the average of five determinations. It is believed that the particle size distributions are representative for this sample.

Seven tests on National Bureau of Standards sample No. 114 b are shown in Table III. The two entries in test No. 1 and four in test No. 2, etc., are redistributions and trials on the same suspension. Tests were made on cement taken from three different ampoules of the standard sample; the first five, the sixth, and the seventh correspond to different sampling. The specific surface in test No. 7 is low. These trials are typical of this particular ampoule. Other ampoules of the standard sample were observed to give uniformly high values, as illustrated in other tables.

In several of the tests of Table III, color filters were introduced into the light path. In others, various lengths of slit and different photocells were used. Such changes in procedure seem to have produced no significant difference in observed values of specific surface.

TABLE V.—DISPERSION TEST (N.B.S. NO. 114 b).

Test	I_{60}	S, sq. cm. per g.
No. 1............	25.8	1980
	25.3	1850
	24.8	1840
No. 2............	36.8	1838
	36.8	1990
Mean......................		1900

As previously mentioned, Table IV illustrates the consistent results obtained for specific surface when the height of fall was changed without making corresponding changes in time schedule. Successive tests were made after the addition of 1 ml. of kerosine, starting with 12 ml. The several entries in each test indicate a redispersion of the suspension. The same ampoule of cement was used in this test and in those of Table VI. Attention is called to the close agreement between the mean values of specific surface, which are about 1 per cent high.

It might be supposed that a 0.05-g. sample is not representative of the cement. On the other hand, the precise results obtained and the agreement between observed and National Bureau of Standards values for various samples indicate that the sampling is satisfactory. To investigate the matter further, 1.3 g. of cement were placed in a flask containing 335 ml. of kerosine. After the addition of a few drops of oleic acid, the sample was dispersed by vigorously shaking the flask. Immediately after placing the flask on the table, 5 ml. of the suspension were transferred from near the bottom of the flask to the absorption cell. After adding 8 ml. of clear kerosine to bring the suspension to standard height, the suspension was tested in the usual manner. Results are shown in Table V. Two different ampoules were used and separate dispersions in 335 ml. made. The results are not markedly different from regular tests, suggesting that the small amounts of cement used are as representative of the sample as the larger masses of cement required in the Wagner procedure.

TABLE VI.—REDISPERSION TEST (N.B.S. NO. 114 b).

Test	Time	I_{60}	S, sq. cm. per g.
No. 1	a.m.	27.8	1968
		25.7	1945
		27.2	1980
		26.7	1955
	p.m.	28.0	1888
		25.2	1860
		25.2	1915
		24.2	1922
No. 2	a.m.	25.1	2018
		26.0	1880
		24.7	1968
		24.8	1928
	p.m.	27.7	1863
		25.8	1902
		26.9	1885
		23.6	1955
No. 3	a.m.	32.1	1950
		31.2	1995
		33.2	1935
		33.2	1905
	p.m.	33.0	1925
		32.8	1900
		30.0	1980
		31.7	1945
Mean			1932

TABLE VII.—DETERMINATION OF r (N.B.S. SAMPLE NO. 114 b).

Test	S, 80μ, sq. cm. per g.	Y_{60} or r	S, 60μ, sq. cm. per g.
No. 1	1932[a]	86.9	1940[a]
	1865[a]	84.4	1915[a]
	1950	93.8	....
	1887	88.8	....
	1903	87.7	....
No. 2	1940	89.5	1920
	....	....	1930
	1923	86.5	1885
	2000	91.9	1910
	1860	74.5	1900
	1972	88.8	1935
No. 3	1890	88.9	1878
	1925	86.6	1880
	1845	77.8	1935
	1965	90.3	1855
No. 4	1852	88.6	1825
	1810	86.4	1855
No. 5	1902	85.4	1918
	1865	83.8	1880
Mean	1900	86.7	1898
Average deviation	±41	±3.1	±28

Value of r indicated by National Bureau of Standards = 88.9.

[a] Obtained from same set of observations.

Table VI illustrates the type of results obtainable when the same dispersion of particles is used over a long period. Three different tests were made using cement from the same ampoule.

Each test consisted of eight trials covering a period of about 6 hr. Two different photocells were used.

The fact that the initial reading in each of the runs in one test are not the same is significant in view of the close agreement among the values of specific surface. The average deviation of the computed values of specific surface is 1.8 per cent and the maximum deviation from the mean is only 4.5 per cent. As explained previously, 0.2 division error in I_{60}, without equal errors in the other observations, will produce an error in S of 4 per cent. It is apparent therefore that a 3 division difference in I_{60} readings as shown in the table cannot be accidental or due to observational error. This suggests that different amounts of cement may have been dispersed in each run and that these were representative of the sample. This effect has been more strikingly observed in powders having a specific surface in excess of 4000 sq. cm. per g. and a particle distribution of 75 per cent below 6 μ in size.

In Table VII data are recorded which indicate that satisfactory specific surface measurements, not involving sieve determinations for r, may be made on portland cement with the Photelometer. Prior to making measurements, the upper size limit of particles in the sample was determined and an appropriate time schedule established. To determine the approximate size of the largest particles in the sample (N.B.S. sample No. 114 b) a suspension was prepared in the usual manner and a study was made of the variation of the transmission factor with time. The transmission of the suspension was constant for about 8.5 sec., corresponding to the time required for 75 μ particles to pass the reference level. Accordingly, the regular portland cement schedule was modified by the addition of intervals for the passage of 80, 75, 70, and 65 μ particles below the reference slit. Since such a schedule was assumed to include all sizes of particles in the sample, 100 was used for the value of r in specific surface calculations. The weight percentages for 60 μ were computed on the basis of the new schedule. For comparison, specific surface values in each test are shown, determined by the standard procedure. With the exception of test No. 1, redispersions were made for each entry in columns three and four.

After a few runs were made to enable the operator to become familiar with the new time schedule, all of the results obtained are shown in Table VII. While these preliminary tests may not be conclusive, they suggest the possibility of eliminating the sieving procedure in specific surface measurements on portland cement.

CONCLUSIONS

1. The unavoidable error in a single measurement of specific surface, using the Wagner procedure with any instrument, is probably 2 per cent.

2. To attain maximum precision, the suspension concentrations should be adjusted to give an initial reading of 30 to 40 divisions.

3. Error in the initial reading affects the computed value of the specific surface to a much greater extent than does an equal error in any other observation.

4. Either equal positive or equal negative errors in all observations may be tolerated since their effect on computed values of specific surface is self-compensating.

5. Differences in height of fall and in temperature of the suspension in different runs introduce errors in the readings. Within practical limits they do not appreciably affect the computed values

of specific surface because they are self-compensating.

6. The more precise signalling clock may replace the timing burette since, in view of conclusion 5, differences in viscosity may be tolerated.

7. Redispersion trials yielding consistent values for specific surface, but yielding widely different initial and final observations, indicate that different amounts of cement are redispersed but that these are accurately representative of the sample.

8. Precise measurements of specific surface and particle size distribution of powdered materials may be made with less than 5 per cent of the materials required for measurement with the Wagner turbidimeter.

9. The small quantity of liquid used makes the doubtful[7] reclamation procedure unnecessary to save kerosine in portland cement tests.

10. The small quantity of suspension required makes adequate dispersion of the particles possible in the observation cell. The time required for dispersing the sample is less than one minute.

11. Test samples may be redispersed for check measurements.

12. The use of an average transmittancy constant to obtain supposedly increased precision in measurement for specific surface of a particular cement is not recommended, since, in view of conclusion 7, it presupposes complete dispersion of *all* of the accurately weighed sample.

13. Preliminary tests indicate that sieve determinations for r may be unnecessary in specific surface measurements on portland cement.

14. Since the resolving power is proportional to h/a, high resolving power may be secured by use of a narrow slit and small height of fall or a wide slit and a large height of fall. To minimize convection current effects and to simplify the experimental technique, the use of a narrow slit appears preferable.

Acknowledgment:

The author wishes to thank O. L. Hay and C. L. Guettel, formerly of this laboratory, for valuable assistance in making this study.

DISCUSSION

Mr. P. S. Roller.[1]—I will not discuss here the larger and more important question as to whether the turbidimeter method is suitable or adequate for determining size distribution. However, certain points are made in this paper that warrant comment. Certainly, the discussion of errors that are made is unsound. It is true, according to Eq. 10, that a compensation takes place if the errors of reading the transmittance are of the same sign, but I see no justification for assuming that the sign will be the same. The same notion of compensating errors is applied to the results of Table IV, but by the law of chance there should be about as many uncompensations as compensations. Table IV seems to imply as much as anything else that the instrument or method is insensitive.

Equation 4 is not worked out, and I have not been able to check it. However, the resulting Eq. 5 is probably erroneous by symmetry considerations. Any departure from equality of the coefficients of the I terms should occur for the extreme I's, namely, $I_{7.5}$ and I_{60}, not I_{10} and I_{60}.

The criticism of Wagner's equation is not valid, as Wagner's derivation does not consider the average particle, but rather the average transmittancy of each interval. To be sure, the Wagner equation has a drastic mathematical limitation, but the reason for this, as I indicated in my discussion of the Ponzer and MacPherson paper of last year,[2] is the non-valid assumption of linearity of the distribution of sizes below 7.5μ.

Mr. M. N. States[3] (*author's closure by letter*).—Formal expansion of the right-hand side of Eq. 4 and insertion of it in Eq. 3 gives Eq. 5, if the d's and I's are given the indicated values. If P_1 is set equal to 3.15 g. per cu. cm., Eq. 5 is identical with Eq. 8 in Wagner's paper,[4] except for the fact that the parenthetical expression in the denominator of Eq. 5 differs from the denominator of Wagner's Eq. 8. The difference arises from the fact that in my summation, of the Wagner type, the entire area above the curve (Wagner Fig. 3) was obtained directly, whereas Wagner summed the greater portion of the area below the curve and subtracted this from the rectangle $ABCD$ to obtain the area above the curve. Wagner states that "the small area between 57.5 and 60μ" was neglected. My alteration of the summation procedure accounts for the difference between Eq. 5 and Wagner's Eq. 8. As suggested in the footnote to Eq. 5, on the assumption that the average particle size within the range 7.5 to 10μ is 7.5μ, the Wagner equation may be obtained by a direct summation of the area above the curve, neglecting, of course, "the small area between 57.5 and 60μ".

The treatment of micron ranges, as indicated above, is somewhat different from Wagner's, hence the fact that the "symmetry" of my coefficients for the I's differs from that of Wagner's is a matter of neither surprise nor importance. Notwithstanding Mr. Roller's opinion, Eq. 5 is correct. The difference between Eq. 5 and Wagner's Eq. 8 for portland cement has been recognized by competent users of the Wagner turbidimeter, and in many instances specific surfaces are computed from the "logical form," Eq. 5. I express no opinion as to the view taken by Mr. Wagner in deriving his equation. If it is true, as Mr. Roller indicates, that the assumption of linearity of the distribution of sizes below 7.5μ is not valid, the difference between the two equations is probably an academic question rather than a practical one.

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[1] Physical Chemist, Eastern Experiment Station, U. S. Bureau of Mines, College Park, Md.

[2] Discussion of paper by H. S. Ponzer and D. R. MacPherson, "Studies of the Operation of the Wagner Turbidimeter," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 458 (1938).

[3] Director of Research and Development, Central Scientific Co., Chicago, Ill.

[4] L. A. Wagner, "A Rapid Method for the Determination of the Specific Surface of Portland Cement," *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 553 (1933).

It is obvious that Eq. 10 is not of the form to indicate the probable error in specific surface measurements. Such use of it was not intended nor made in the paper. The analysis by means of which Eq. 10 is derived from the Wagner equation is well known and is generally recognized as effective in examining working equations for significant sources of error. The procedure is also helpful in establishing instrumental techniques.

With Eq. 10, I made two—and only two—points in the paper. The first is that in the case of chance errors a given relative error in the first observation, in this case I_{60}, has much more effect on the specific area determination than do errors of the same size in the subsequent observations. The fact that chance errors would be about equally positive and negative was considered too obvious to require formal statement. However, it is this fact which causes all chance $\frac{\Delta I}{I}$ values—except for the first observation—to tend to cancel out and thus to emphasize the importance of the first $\frac{\Delta I}{I}$. The second point made with Eq. 10 is that if there are systematic sources of error which produce equal errors, either all positive or all negative, in the microammeter indications, the eleven negative contributions to error in specific surface largely offset the effect of the error introduced in the first reading. Anyone having access to data taken on a Wagner instrument may easily confirm these conclusions predicted by Eq. 10.

Table IV is in no wise a reflection on the sensitivity of the instrument or method, nor does it have to do with chance errors. It shows that if a systematic error is introduced into the experiment the value of the specific surface determination is practically unchanged. As shown by Eq. 10, this must necessarily be the case and has nothing to do with sensitivity.

It is a matter of regret that these points were apparently not made sufficiently clear in the paper.

LEAN CONCRETE MIXES—A STUDY OF THE EFFECT OF CEMENT CONTENT, CEMENT FINENESS ON COMPRESSIVE STRENGTH, DURABILITY AND VOLUME CHANGE OF CONCRETE

By Ernst Gruenwald[1]

Synopsis

During 1938 a series of tests was carried out at the Research Laboratory of the Lone Star Cement Corp. at Hudson, N. Y., to study the properties of lean concrete mixes. A portland cement ground to three finenesses and a high-early-strength portland cement ground to two finenesses were used. The effect of finely ground limestone as a "filler" was also studied. Aggregates were sand and gravel graded up to 1½ in.

Seven concrete mixes were made with cement contents ranging from two to six bags per cubic yard. Six similar mixes were made using enough filler to make the sum of absolute volumes of cement and filler equal to that of five bags of cement. The concretes had two consistencies, represented by 2-in. and 6-in. slumps.

Determinations of strength, durability, volume change and modulus of elasticity were made for different curing conditions. The report covers data through the age of three months; strength specimens will be tested to the age of 10 yr.

Conclusions are drawn on the effect of cement fineness and type, and additions of filler, on the properties of concrete.

In the 21 yr. since the water-cement ratio law was established by Abrams in 1918, widespread research on cement and concrete has not only resulted in better control of concrete in the field, but has also greatly improved the strength-giving properties of portland cement, with the result that normal commercial mixes today produce strengths far in excess of the 2000 to 2500 psi. so often specified at 28 days. Strengths in excess of 3000 and 4000 psi. at 28 days are not unusual.

In view of this, when strengths alone are specified and mixes designed accordingly, the cement content is frequently reduced to a point where the concrete lacks workability, where it segregates, bleeds and is of doubtful durability. With modern cements, strengths of 2000 or 2500 psi. are no assurance of a durable concrete. The Joint Committee on Concrete and Reinforced Concrete has recognized this and advocates proportioning for durability as dictated by exposure, as well as for strength.[2]

Many previous investigations have shown the effect of cement content on strength for mixes containing five or more bags of cement per cubic yard.

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[1] Engineer, "Incor" Division, Lone Star Cement Corp., New York City.

[2] Progress Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, January, 1937.

TABLE I.—CHEMICAL ANALYSES AND PHYSICAL TESTS OF CEMENTS AND FILLER.

	Filler	Portland Cements			High-Early-Strength Portland Cements	
		Surface Area 1745 sq. cm. per g.	Surface Area 2160 sq. cm. per g.	Surface Area 2520 sq. cm. per g.	Surface Area 2440 sq. cm. per g.	Surface Area 2655 sq. cm. per g.
CHEMICAL ANALYSIS, PER CENT						
SiO_2	13.90	19.76	19.70	20.08	19.23	19.07
Al_2O_3	5.23	7.73	7.84	7.82	7.03	7.07
FeO_3	2.87	3.55	3.56	3.54	3.51	3.50
CaO	41.35	64.45	64.45	64.30	65.30	65.15
MgO	0.72	1.12	1.05	1.07	1.09	1.12
SO_3	1.34	1.84	1.72	1.85	2.20	2.49
Loss	33.73	0.87	0.78	0.80	0.87	0.88
Total	99.14	99.32	99.10	99.46	99.23	99.28
COMPOUND COMPOSITION, PER CENT						
C_3S	.....	47.3	47.6	43.0	58.4	57.8
C_2S	.....	21.1	20.6	25.2	11.1	11.1
C_3A	.....	14.5	14.7	14.7	12.7	12.8
C_4AF	.....	10.8	10.8	10.8	10.7	10.6
$CaSO_4$	.....	3.1	2.9	3.1	3.7	4.2
Free MgO	.....	1.1	1.1	1.1	1.1	1.1
Free CaO	.....	0.54	0.56	0.77	0.65	0.67
Loss	.....	0.87	0.78	0.80	0.88	0.88
FINENESS						
No. 200 mesh	91.4	97.2	99.0	99.8	99.9	99.9
No. 325 mesh	90.6	93.6	97.7	98.7	98.7	99.5
PARTICLE SIZE DISTRIBUTION						
60-micron						
55	87.0	91.6	97.7	98.7	98.2	99.6
50	85.3	89.9	97.0	97.9	98.2	99.5
45	82.6	86.5	96.7	96.2	97.4	99.5
40	79.8	82.6	92.9	94.0	95.5	99.5
35	75.5	77.4	88.2	93.0	91.8	96.0
30	71.8	70.2	83.3	87.5	86.9	91.3
25	68.1	60.6	74.5	80.4	79.4	84.1
20	64.0	50.7	64.1	69.6	69.5	75.7
15	59.5	37.9	48.4	57.2	55.3	61.5
10	54.6	25.7	34.5	42.8	41.0	45.9
7.5	52.2	20.1	27.2	34.8	32.8	37.6
Surface area, sq. cm. per g.	3450	1745	2160	2520	2440	2655
Specific Gravity	2.71	3.15	3.16	3.16	3.15	3.16
PHYSICAL TESTS						
Setting time:						
Initial	.....	3:25	2:55	2:25	2:00	2:05
Final	.....	5:50	4:55	4:35	4:20	4:15
Normal consistency, per cent	36.0	28.0	30.0	30.0	27.5	28.0
Tensile strength, psi. 1:3 standard briquets						
1 day	.....	86	93	143	308	332
3 days	.....	307	331	391	444	460
7 days	.....	397	429	460	509	519
28 days	.....	476	504	507	536	513
PHYSICAL TESTS (*Continued*)						
Compressive strength, psi. 1:2.77 plastic mortar 2-in. cubes						
1 day	.....	340	420	570	1335	1725
3 days	.....	1465	2405	2940	3750	4095
7 days	.....	2715	3665	3985	4855	5320
28 days	.....	4235	5085	5745	6275	6240
Heat of hydration, cal. per g.						
1 day	.....	55	60	61	64	70
7 days	.....	91	91	100	94	102
28 days	.....	98	102	103	102	108
3 months	.....	105	104	105	111	108

The present study was undertaken to determine the effect of cement contents in the leaner range, not only on strength, but also on durability and volume change. To offset the deficiencies in fines of the leaner mixes, finer cements are often demanded and resort is also had to admixtures or fillers. For these reasons different finenesses of cement and the effect of an inert filler were studied in the present investigation.

The test program required molding 8280 of the 6 by 12-in. concrete cylinders, 690 of the 6 by 6 by 3-in. blocks for freezing-and-thawing tests, and 1380 of the 3 by 3 by 12-in. beams for volume change observations. Stress-strain relations were determined for 2070 of the cylinders. Eleven months were required in making the test specimens.

MATERIALS USED IN TESTS

Cement:

Two cements, each of different finenesses, from the Lone Star Mill at Dallas, Tex., were used. One was a standard portland cement, ground to three finenesses—1745, 2160, 2520 sq. cm. per g. surface area; the other was high-early-strength cement ground to two finenesses—2440 and 2655 sq. cm. per g. Complete physical and chemical tests are given in Table I. All five samples complied with the appropriate A.S.T.M. specifications.

Filler:

Pulverized limestone used as filler was from the Dallas plant. The specific gravity was 2.71; specific surface, 3450;[3] and normal consistency, 36.0 per cent.

Aggregates:

Principal characteristics of the aggregates are shown in the following table:

Size	Origin	Specific Gravity	Fineness Modulus	Weight, lb. per cu.ft.	Proportion
0 to No. 4	Long Island	2.66	2.26[a]	103.2	Variable
No. 4 to ⅜ in.	Long Island	2.66	7.26	101.6	30%
⅜ in. to ¾ in.	Long Island	2.66			40%
¾ in. to 1½ in.	Great Barrington	2.64			30%

[a] About 23 per cent passing the No. 50 sieve and 5 per cent passing the No. 100 sieve.

Concrete Mixes:

Prior to starting the tests a preliminary series of mixes was made to determine the optimum sand contents and also optimum amounts of filler. In this, 166 hand-mixed batches were made. Five sand percentages were used for each cement content, and three percentages of filler. The tests were made with the same cements and aggregates as used in the main series. Proportioning of materials was based on the result of these tests. The quantities for the different batches are shown below:

PLAIN CONCRETE

Cement, bags per cu. yd...	2	2½	3	3½	4	5	6
Cement, lb....	15	19	23	26	30	37	44
Sand, lb......	123	118	114	107	104	93	85
Graded gravel, lb..........	153	154	157	156	158	163	165

CONCRETE WITH FILLER

Cement, bags per cu. yd..	2	2½	3	3½	4	5
Filler, bags per cu. yd.[a].	3	2½	2	1½	1	1
Cement, lb....	15	19	23	26	30	37
Filler, lb......	19.35	16.3	13.2	9.6	6.45	6.35
Sand, lb......	94	95	96	94	96	93
Graded gravel, lb..........	160	162	164	161	164	160

[a] Equal to 1 bag of cement by absolute volume (80.8 lb.).

TEST PROCEDURE

Mixing:

All batches were machine mixed for 5 min. in a small "Wonder" mixer. About 3 min. of this time were required to obtain uniformity. Addition of water was regulated to produce uniform slumps of either 2 in. or 6 in. Temperatures of all materials and air in the mixing room were controlled at 70 ± 1 F. In all cases, except where noted, each result reported is the average of three specimens, one each from three identical batches mixed on different days.

Molding Specimens:

Each batch, containing about 2 cu. ft., was sufficient for the following specimens: Eight 6 by 12-in. cylinders, for test at 1, 3, 7, and 28 days, 3 months, 1, 5, and 10 yr.; four 3 by 3 by 12-in. volume change beams for various storages up to 1 yr.; and two 6 by 6 by 3-in. blocks for freezing-and-thawing tests. All specimens were rodded into steel molds and finished with a steel trowel. Cylinders were capped with neat high-early-strength cement 3 to 4 hr. after molding. Slump, flow, and unit weight of fresh concrete were determined on all batches according to A.S.T.M. methods.

Curing:

Specimens remained covered in molds for 20 to 22 hr. and were then stored according to the desired curing condition. Moist-cured specimens were

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[3] Specific surface is the surface area in square centimeters per gram.

TABLE II.—COMPRESSION TESTS OF PLAIN CONCRETE AND CONCRETE WITH FILLER.

Portland Cement—Surface Area, 1745 sq. cm. per g.

Sand and gravel: Long Island, N. Y. *Filler:* Pulverized limestone from Dallas, Tex.

Machine-mixed concrete: 8 cylinders from each batch. *Strengths* are averages of specimens from 3 batches mixed on different days; 9 tests at 1 day, 3 tests at other ages. Cylinders tested as cured.

Nominal Mix, bags per cu. yd.		Curing Condition	Water-Cement Ratio by Volume[b]	Flow, per cent	Unit Weight, lb. per cu. ft.	Compressive Strength, psi.				
Cement	Filler[a]					1 day	3 days	7 days	28 days	3 months
				PLAIN CONCRETE—2-IN. SLUMP						
2	..	Moist	2.76	160	141.6	50	135	205	425	470
2½	..		2.18	182	142.7	60	205	460	720	920
3	..		1.63	170	143.9	100	495	795	1265	1590
3½	..		1.39	170	145.3	165	775	1165	1885	2300
4	..		1.18	158	145.7	260	1165	1640	2625	3125
5	..		0.90	156	148.4	480	2180	3075	4675	4915
6	..		0.75	151	149.7	680	2800	3365	5155	5835
2	..	3 days moist then air	2.76	160	141.6	50	125	310	435	375
2½	..		2.18	182	142.7	60	205	515	785	710
3	..		1.63	170	143.9	100	525	995	1345	1180
3½	..		1.39	170	145.3	165	815	1315	1985	1685
4	..		1.18	158	145.7	260	1145	1785	2705	2405
5	..		0.90	156	148.7	480	1945	3210	4435	3845
6	..		0.75	151	149.7	680	2615	3595	4845	4975
2	..	1 day moist then air	2.76	160	141.6	50	190	300	365	400
2½	..		2.18	182	142.7	60	225	520	650	640
3	..		1.63	170	143.9	100	495	910	1075	975
3½	..		1.39	170	145.3	165	720	1220	1745	1545
4	..		1.18	158	145.7	260	1060	1735	2225	2065
5	..		0.90	156	148.7	480	1865	2805	3295	3195
6	..		0.75	151	149.7	680	2395	3420	4155	4145
				CONCRETE WITH FILLER—2-IN. SLUMP						
2	3	Moist	2.58	159	145.3	115	335	555	870	1105
2½	2½		1.99	159	145.8	160	615	900	1340	1670
3	2		1.60	159	146.8	295	895	1285	1805	2230
3½	1½		1.41	166	147.3	350	1155	1650	2310	2705
4	1		1.18	158	147.6	430	1580	2380	3205	3330
5	1		0.95	153	148.4	630	2270	3075	3900	4750
2	3	3 days moist then air	2.58	159	145.3	115	355	570	875	995
2½	2½		1.99	159	145.8	160	635	955	1305	1475
3	2		1.60	159	146.8	295	895	1445	2015	2155
3½	1½		1.41	166	147.3	350	1145	1815	2460	2675
4	1		1.18	158	147.6	430	1600	2320	3245	3135
5	1		0.95	153	148.4	630	2300	3205	4180	4315
2	3	1 day moist then air	2.58	159	145.3	115	340	495	660	695
2½	2½		1.99	159	145.8	160	600	815	1035	1210
3	2		1.60	159	146.8	295	835	1055	1365	1560
3½	1½		1.41	166	147.3	350	1015	1435	1775	1825
4	1		1.18	158	147.6	430	1380	2110	2430	2485
5	1		0.95	153	148.4	630	2195	2770	3350	3400
				PLAIN CONCRETE—6-IN. SLUMP						
3½	..	Moist	1.57	205	144.5	125	575	940	1480	1750
4	..		1.34	201	145.4	165	875	1215	2205	2360
5	..		0.98	191	147.4	400	1655	2355	3775	4445
6	..		0.81	178	148.8	660	2385	3450	5065	5340
3½	..	3 days moist then air	1.57	205	144.5	125	565	965	1315	1390
4	..		1.34	201	145.4	165	740	1305	2030	2025
5	..		0.98	191	147.4	400	1775	2635	3515	3670
6	..		0.81	178	148.8	660	2295	3490	4505	4650
3½	..	1 day moist then air	1.57	205	144.5	125	515	915	1055	1170
4	..		1.34	201	145.4	165	760	1150	1585	1455
5	..		0.98	191	147.4	400	1560	1915	2860	3155
6	..		0.81	178	148.8	660	2295	3025	4085	4255
				CONCRETE WITH FILLER—6-IN. SLUMP						
2	3	Moist	2.83	173	144.5	100	255	365	585	775
2½	2½		2.23	179	145.0	165	430	655	1010	1065
3	2		1.84	184	145.6	215	670	1015	1495	1725
3½	1½		1.54	186	146.1	280	935	1465	1995	2275
4	1		1.34	196	146.8	295	1175	1840	2540	2835
5	1		1.09	189	146.7	440	1765	2575	3185	3925
2	3	3 days moist then air	2.83	173	144.5	100	275	470	555	680
2½	2½		2.23	179	145.0	165	465	745	950	1075
3	2		1.84	184	145.6	215	700	1075	1405	1615
3½	1½		1.54	186	146.1	280	945	1465	1945	2025
4	1		1.34	196	146.8	295	1175	1840	2405	2660
5	1		1.09	189	146.7	440	1835	2785	3500	3825
2	3	1 day moist then air	2.83	173	144.5	100	255	385	465	510
2½	2½		2.23	179	145.0	165	430	610	700	905
3	2		1.84	184	145.6	215	595	915	1125	1260
3½	1½		1.54	186	146.1	280	845	1255	1525	1565
4	1		1.34	196	146.8	295	1025	1625	1970	2085
5	1		1.09	189	146.7	440	1515	2195	2565	2835

[a] 1 bag of filler (80.8 lb.) is equal by absolute volume to 1 bag of cement.

[b] Water-cement ratio based on cement only.

kept in a fog room in a saturated atmosphere having temperature controlled at 70 ± 1 F. Air-cured cylinders were stored in laboratory air at 70 to 75 F. but humidity was not controlled. Identical sets of cylinders as molded were cured as follows:

(*a*) 1 day in molds, then in fog room.
(*b*) 1 day in molds, 2 days in fog room, then in air.
(*c*) 1 day in molds, then in laboratory air.

All specimens were tested in the condition cured.

TABLE III.—COMPRESSION TESTS OF PLAIN CONCRETE AND CONCRETE WITH FILLER.

Portland Cement—Surface Area 2160 sq. cm. per g.

Sand and gravel: Long Island, N. Y. *Filler:* Pulverized limestone from Dallas, Tex.

Machine-mixed concrete: 8 cylinders from each batch.

Strengths are averages of specimens from 3 batches mixed on different days; 9 tests at 1 day, 3 tests at other ages. Cylinders tested as cured.

Nominal Mix, bags per cu. yd.		Curing Condition	Water-Cement Ratio by Volume[b]	Flow, per cent	Unit Weight, lb. per cu. ft.	Compressive Strength, psi				
Cement	Filler[a]					1 day	3 days	7 days	28 days	3 months
PLAIN CONCRETE—2-IN. SLUMP										
2	..	Moist	2.64	167	141.9	65	220	325	435	555
2½	..		2.06	162	144.1	85	375	605	865	995
3	..		1.69	166	144.8	105	565	845	1315	1580
3½	..		1.40	172	146.1	230	950	1395	2225	2365
4	..		1.15	164	147.6	340	1595	2080	3235	3585
5	..		0.87	153	149.4	640	2445	3565	5095	5630
6	..		0.74	149	150.4	965	3175	4345	5710	6565
2	..	3 days moist then air	2.64	167	141.9	65	215	380	675	495
2½	..		2.06	162	144.1	85	395	720	1040	810
3	..		1.69	166	144.8	105	595	925	1450	1285
3½	..		1.40	172	146.1	230	960	1470	2250	1885
4	..		1.15	164	147.6	340	1515	2365	3260	2755
5	..		0.87	153	149.4	640	2505	3905	5005	4665
6	..		0.74	149	150.4	965	3480	4315	5755	5515
2	..	1 day moist then air	2.64	167	141.9	65	220	385	585	505
2½	..		2.06	162	144.1	85	360	600	930	805
3	..		1.69	166	144.8	105	545	985	1375	1195
3½	..		1.40	172	146.1	230	960	1475	1910	1760
4	..		1.15	164	147.6	340	1455	2045	2885	2525
5	..		0.87	153	149.4	640	2335	3080	4080	3720
6	..		0.74	149	150.4	965	2765	3955	4895	4580
CONCRETE WITH FILLER—2-IN. SLUMP										
2	3	Moist	2.51	157	145.9	150	455	585	945	1035
2½	2½		1.96	157	146.2	265	760	995	1425	1595
3	2		1.63	160	146.9	290	1080	1435	2090	2495
3½	1½		1.35	158	147.7	390	1605	2205	3015	3315
4	1		1.17	159	148.4	520	1990	2595	3595	3925
5	1		0.97	162	148.9	770	2640	3340	4385	4885
2	3	3 days moist then air	2.51	157	145.9	150	435	690	975	965
2½	2½		1.96	157	146.2	265	770	1185	1620	1600
3	2		1.63	160	146.9	290	1095	1630	2135	2215
3½	1½		1.35	158	147.7	390	1565	2365	3000	3115
4	1		1.17	159	148.4	520	1905	2705	3250	3350
5	1		0.97	162	148.9	770	2565	3335	4300	4040
2	3	1 day moist then air	2.51	157	145.9	150	420	610	755	760
2½	2½		1.96	157	146.2	265	695	950	1255	1220
3	2		1.63	160	146.9	290	955	1330	1875	1785
3½	1½		1.35	158	147.7	390	1400	1940	2460	2375
4	1		1.17	159	148.4	520	1575	2305	2875	2675
5	1		0.97	162	148.9	770	2365	3260	3685	3715
TABLE III.—*Continued*										
PLAIN CONCRETE—6-IN. SLUMP										
3½	..	Moist	1.41	199	146.7	215	970	1270	1885	2120
4	..		1.23	200	147.6	300	1315	1825	2685	2975
5	..		0.94	189	149.5	480	2215	3085	4415	4695
6	..		0.80	181	150.0	550	2975	3955	5125	5440
3½	..	3 days moist then air	1.41	199	146.7	215	980	1475	2195	1845
4	..		1.23	200	147.6	300	1330	1915	2795	2440
5	..		0.94	189	149.5	480	2180	3275	3960	3975
6	..		0.80	181	150.0	550	2995	4025	4690	4875
3½	..	1 day moist then air	1.41	199	146.7	215	905	1315	1700	1480
4	..		1.23	200	147.6	300	1330	1855	2115	2215
5	..		0.94	189	149.5	480	2295	3115	3755	3865
6	..		0.80	181	150.0	550	2640	3380	4380	4850
CONCRETE WITH FILLER—6-IN. SLUMP										
2	3	Moist	2.75	177	145.3	140	325	440	665	810
2½	2½		2.11	182	146.3	190	595	790	1210	1380
3	2		1.77	181	146.8	245	860	1200	1730	1955
3½	1½		1.47	181	147.5	340	1275	1665	2355	2570
4	1		1.23	184	148.0	425	1595	2225	3055	3230
5	1		1.01	181	148.9	605	2215	3190	4160	4325
2	3	3 days moist then air	2.75	177	145.3	140	345	565	745	805
2½	2½		2.11	182	146.3	190	595	1045	1320	1395
3	2		1.77	181	146.8	245	840	1295	1700	1865
3½	1½		1.47	181	147.5	340	1215	1730	2255	2515
4	1		1.23	184	148.0	425	1760	2480	3210	3215
5	1		1.01	181	148.9	605	2175	3335	3890	4025
2	3	1 day moist then air	2.75	177	145.3	140	300	495	545	525
2½	2½		2.11	182	146.3	190	575	875	1015	1025
3	2		1.77	181	146.8	245	775	1185	1375	1405
3½	1½		1.47	181	147.5	340	1155	1595	1795	1925
4	1		1.23	184	148.0	425	1585	2135	2220	2435
5	1		1.01	181	148.9	605	2085	2755	2870	3150

[a] 1 bag of filler (80.8 lb.) is equal by absolute volume to 1 bag of cement.

[b] Water-cement ratio based on cement only.

Volume change beams were cured 1 day in molds and then as follows:

(*a*) In air at 70 F. and 50 to 55 per cent relative humidity.

(*b*) In water at 70 F.

(*c*) 6 days in water, then in air at 70 F. and 50 to 55 per cent relative humidity.

(*d*) 13 days in water, then 15 days alternately in air and water.

TABLE IV.—COMPRESSION TESTS OF PLAIN CONCRETE AND CONCRETE WITH FILLER.

Portland Cement—Surface Area 2520 sq. cm. per g.

Sand and Gravel: Long Island, N. Y. *Filler:* Pulverized limestone from Dallas, Tex.

Machine-mixed concrete: 8 cylinders from each batch.

Strengths are averages of specimens from 3 batches mixed on different days; 9 tests at 1 day, 3 tests at other ages. Cylinders tested as cured.

Nominal Mix, bags per cu. yd.		Curing Condition	Water-Cement Ratio by Volume[b]	Flow, per cent	Unit Weight, lb. per cu. ft.	Compressive Strength, psi.				
Cement	Filler[a]					1 day	3 days	7 days	28 days	3 months
					PLAIN CONCRETE—2-IN. SLUMP					
2	..	Moist	2.77	164	143.3	65	265	385	535	565
2½	..		2.10	173	144.5	105	400	595	835	895
3	..		1.63	170	145.6	175	770	1085	1585	1620
3½	..		1.36	172	146.4	275	1065	1555	2370	2540
4	..		1.12	160	147.6	410	1880	2400	3765	3675
5	..		0.86	158	150.0	990	3175	4130	5190	5605
6	..		0.72	148	150.6	1470	3865	4765	5835	6490
2	..	3 days moist then air	2.77	164	143.3	65	235	360	565	465
2½	..		2.10	173	144.5	105	410	655	985	835
3	..		1.63	170	145.6	175	710	1090	1665	1355
3½	..		1.36	172	146.4	275	1075	1735	2330	2145
4	..		1.12	160	147.6	410	1930	2855	3595	3165
5	..		0.86	158	150.0	990	3085	3860	5105	4995
6	..		0.72	148	150.6	1470	3880	4975	5975	6035
2	..	1 day moist then air	2.77	164	143.3	65	230	350	515	465
2½	..		2.10	173	144.5	105	395	705	945	775
3	..		1.63	170	145.6	175	665	1060	1375	1195
3½	..		1.36	172	146.4	275	1070	1665	2080	1870
4	..		1.12	160	147.6	410	1665	2465	2755	2635
5	..		0.86	158	150.0	990	2850	3715	4720	4455
6	..		0.72	148	150.6	1470	3725	4440	5450	5495
					CONCRETE WITH FILLER—2-IN. SLUMP					
2	3	Moist	2.49	161	146.3	200	535	765	1065	1090
2½	2½		1.93	158	147.1	325	870	1220	1620	1605
3	2		1.58	151	147.8	490	1365	1815	2420	2360
3½	1½		1.36	163	148.2	600	1720	2260	3030	3045
4	1		1.15	158	148.9	710	2365	3020	4030	4060
5	1		0.92	146	149.1	1295	3185	4165	5060	5645
2	3	3 days moist then air	2.49	161	146.3	200	545	875	1140	1145
2½	2½		1.93	158	147.1	325	950	1415	1825	1850
3	2		1.58	151	147.8	490	1460	1945	2475	2730
3½	1½		1.36	163	148.2	600	1805	2480	3095	3105
4	1		1.15	158	148.9	710	2250	3195	3930	4125
5	1		0.92	146	149.1	1295	3625	4200	5020	3095
2	3	1 day moist then air	2.49	161	146.3	200	520	775	930	995
2½	2½		1.93	158	147.1	325	845	1245	1445	1580
3	2		1.58	151	147.8	490	1265	1805	2075	2145
3½	1½		1.36	163	148.2	600	1675	2265	2525	2545
4	1		1.15	158	148.9	710	2125	2785	3230	3220
5	1		0.92	146	149.1	1295	3310	3880	4310	4510

[a] 1 bag of filler (80.8 lb.) is equal by absolute volume to 1 bag of cement.

[b] Water-cement ratio based on cement only.

TABLE IV.—*Continued*

Nominal Mix, bags per cu. yd.		Curing Condition	Water-Cement Ratio by Volume[b]	Flow, per cent	Unit Weight, lb. per cu. ft.	Compressive Strength, psi.				
Cement	Filler[a]					1 day	3 days	7 days	28 days	3 months
					PLAIN CONCRETE—6-IN. SLUMP					
3½	..	Moist	1.45	202	146.1	230	995	1375	2175	2245
4	..		1.24	199	147.1	330	1415	1880	2835	3140
5	..		0.92	184	149.0	730	2785	3485	4680	5250
6	..		0.77	174	149.5	1030	3320	4215	5310	5780
3½	..	3 days moist then air	1.45	202	146.1	230	935	1435	2110	1980
4	..		1.24	199	147.1	330	1370	2245	2890	2700
5	..		0.92	184	149.0	730	2660	3535	4380	4590
6	..		0.77	174	149.5	1030	3215	4320	5035	4945
3½	..	1 day moist then air	1.45	202	146.1	230	1015	1380	1955	1895
4	..		1.24	199	147.1	330	1355	2105	2635	2635
5	..		0.92	184	149.0	730	2585	3095	3985	4400
6	..		0.77	174	149.5	1030	3080	4005	4805	5245
					CONCRETE WITH FILLER—6-IN. SLUMP					
2	3	Moist	2.74	182	145.8	160	410	615	785	905
2½	2½		2.09	183	147.0	230	680	885	1375	1435
3	2		1.66	178	146.8	385	1125	1435	1925	2220
3½	1½		1.39	178	147.4	540	1645	1945	2500	2820
4	1		1.23	188	148.2	610	1970	2505	3210	3490
5	1		1.02	182	148.6	930	2645	3285	4140	4420
2	3	3 days moist then air	2.74	182	145.8	160	420	595	845	900
2½	2½		2.09	183	147.0	230	720	1175	1495	1445
3	2		1.66	178	146.8	385	1145	1645	2055	2220
3½	1½		1.39	178	147.4	540	1550	2165	2670	2825
4	1		1.23	188	148.2	610	2030	2815	3345	3565
5	1		1.02	182	148.6	930	2595	3580	4120	4440
2	3	1 day moist then air	2.74	182	145.8	160	385	555	675	755
2½	2½		2.09	183	147.0	230	690	970	1175	1215
3	2		1.66	178	146.8	385	1125	1400	1710	1870
3½	1½		1.39	178	147.4	540	1480	1965	2415	2405
4	1		1.23	188	148.2	610	1710	2305	2645	2565
5	1		1.02	182	148.6	930	2600	3315	3805	3785

Freezing-and-Thawing Tests:

Specimens after 1 day in molds were cured in 70 F. water until ages of 3 and 28 days, when freezing-and-thawing cycles were started. Specimens were frozen to −20 F. in 2 hr., and thawed to 70 F. in about 3 hr. They were completely immersed during the cycles. Losses in weight were recorded, and the blocks were discarded after a 25 per cent loss in weight. Due to the method of curing and the rapid reversals in temperature, the tests were unusually severe.

TABLE V.—COMPRESSION TESTS OF PLAIN CONCRETE AND CONCRETE WITH FILLER.

High-Early-Strength Portland Cement—Surface Area 2440 sq. cm. per g.

Sand and Gravel: Long Island, N. Y. *Filler:* Pulverized limestone from Dallas, Tex.
Machine-mixed concrete: 8 cylinders from each batch.
Strengths are averages of specimens from 3 batches mixed on different days; 9 tests at 1 day, 3 tests at other ages. Cylinders tested as cured.

Nominal Mix, bags per cu. yd.		Curing Condition	Water-Cement Ratio by Volume[b]	Flow, per cent	Unit Weight, lb. per cu. ft.	Compressive Strength, psi.				
Cement	Dust[a]					1 day	3 days	7 days	28 days	3 months
		PLAIN CONCRETE—2-IN. SLUMP								
2	..	Moist	2.65	162	142.7	170	430	565	585	655
2½	..		2.07	158	144.0	295	710	925	1015	1020
3	..		1.63	160	145.3	435	1165	1515	1745	1600
3½	..		1.39	162	146.7	705	1805	2225	2505	2415
4	..		1.14	158	147.9	1085	2630	3180	3745	3630
5	..		0.88	149	149.1	1795	3720	4360	4915	5415
6	..		0.74	147	150.7	2530	4475	5360	5790	6395
2	..	3 days moist then air	2.65	162	142.7	170	375	600	780	695
2½	..		2.07	158	144.0	295	705	1000	1295	1190
3	..		1.63	160	145.3	435	1175	1565	2045	1895
3½	..		1.39	162	146.7	705	1825	2485	2945	2725
4	..		1.14	158	147.9	1085	2540	3205	3685	3570
5	..		0.88	149	149.1	1795	3655	4870	5575	5255
6	..		0.74	147	150.7	2530	4500	5765	6495	6195
2	..	1 day moist then air	2.65	162	142.7	170	400	605	655	625
2½	..		2.07	158	144.0	295	705	955	1095	1040
3	..		1.63	160	145.3	435	1160	1545	1705	1625
3½	..		1.39	162	146.7	705	1745	2135	2455	2265
4	..		1.14	158	147.9	1085	2530	3215	3535	3320
5	..		0.88	149	149.1	1795	3225	4155	4705	4465
6	..		0.74	147	150.7	2530	4250	5300	6055	5700
		CONCRETE WITH FILLER—2-IN. SLUMP								
2	3	Moist	2.44	149	146.6	380	805	925	1135	1095
2½	2½		1.93	152	147.1	615	1205	1505	1635	1755
3	2		1.58	151	147.8	750	1700	2105	2375	2175
3½	1½		1.37	156	147.7	950	2245	2725	2950	2970
4	1		1.16	150	148.6	1275	2825	3520	3820	3920
5	1		0.95	149	148.7	1965	3875	4715	5105	5380
2	3	3 days moist then air	2.44	149	146.6	380	760	1085	1405	1585
2½	2½		1.93	152	147.1	615	1560	1595	2010	2165
3	2		1.58	151	147.8	750	1765	2065	2905	2990
3½	1½		1.37	156	147.7	950	2245	2865	3495	3395
4	1		1.16	150	148.6	1275	2895	3775	4220	4040
5	1		0.95	149	148.7	1965	3880	4995	5380	4910
2	3	1 day moist then air	2.44	149	146.6	380	795	1090	1230	1295
2½	2½		1.93	152	147.1	615	1215	1595	1805	1930
3	2		1.58	151	147.8	750	1760	2155	2435	2295
3½	1½		1.37	156	147.7	950	2195	2695	3085	2935
4	1		1.16	150	148.6	1275	2795	3490	3715	3570
5	1		0.95	149	148.7	1965	3865	4545	4855	4545
		PLAIN CONCRETE—6 IN. SLUMP								
3½	..	Moist	1.45	192	146.9	655	1575	2010	2405	2355
4	..		1.25	188	147.5	775	1840	2370	2835	2985
5	..		0.94	172	149.2	1545	3135	3930	4525	4895
6	..		0.80	170	149.9	2050	3920	4365	5170	5665
3½	..	3 days moist then air	1.45	192	146.9	655	1555	2045	2535	2515
4	..		1.25	188	147.5	775	1925	2665	3375	3075
5	..		0.94	172	149.2	1545	3075	4025	4635	4435
6	..		0.80	170	149.9	2050	3705	4815	5585	5465
3½	..	1 day moist then air	1.45	192	146.9	655	1445	1895	2245	2165
4	..		1.25	188	147.5	775	1940	2315	2905	2805
5	..		0.94	172	149.2	1545	2980	3075	4330	4245
6	..		0.80	170	149.9	2050	4015	4450	5320	5035
		CONCRETE WITH FILLER—6-IN. SLUMP								
2	3	Moist	2.68	173	146.4	255	590	700	885	980
2½	2½		2.12	177	146.6	385	840	1130	1405	1460
3	2		1.75	178	146.7	530	1295	1615	1860	1950
3½	1½		1.45	172	147.3	785	1940	2355	2655	2805
4	1		1.28	178	147.9	975	2295	2805	3185	3205
5	1		1.06	174	148.5	1465	3195	3735	4385	4655
2	3	3 days moist then air	2.68	173	146.4	255	590	835	1125	1235
2½	2½		2.12	177	146.6	385	915	1315	1650	1765
3	2		1.75	178	146.7	530	1275	1825	2115	2420
3½	1½		1.45	172	147.3	785	1950	2765	3195	3215
4	1		1.28	178	147.9	975	2365	3215	3565	3525
5	1		1.06	174	148.5	1465	3260	4090	4705	4305
2	3	1 day moist then air	2.68	173	146.4	255	615	765	975	1075
2½	2½		2.12	177	146.6	385	885	1235	1395	1515
3	2		1.75	178	146.7	530	1270	1590	1835	1905
3½	1½		1.45	172	147.3	785	1875	2380	2650	2660
4	1		1.28	178	147.9	975	2305	2900	3145	3180
5	1		1.06	174	148.5	1465	3125	3705	4045	3875

[a] 1 bag of filler (80.8 lb.) is equal by absolute volume to 1 bag of cement.

[b] Water-cement ratio based on cement only.

Modulus of Elasticity:

Deformation readings were made on 2 cylinders from each batch at 7 and 28 days for high-early-strength cement, and at 28 days and 3 months for portland-cement concrete. The compressometer was similar to the Olsen single dial type, having two fixed rings attached to the concrete by three set screws, and one rotating ring to which movement was transmitted by a steel spindle. Deformations were read to 0.0001 in. Readings were taken at 10,000-lb. increments up to 60,000-lb. total load.

TABLE VI.—COMPRESSION TESTS OF PLAIN CONCRETE AND CONCRETE WITH FILLER.

High-Early-Strength Portland Cement—Surface Area 2655 sq. cm. per g.

Sand and Gravel: Long Island, N. Y. *Filler:* Pulverized limestone from Dallas, Tex.

Machine-mixed concrete: 8 cylinders from each batch.

Strengths are averages of specimens from 3 batches mixed on different days; 9 tests at 1 day, 3 tests at other ages. Cylinders tested as cured.

Nominal Mix, bags per cu. yd.		Curing Condition	Water-Cement Ratio by Volume[b]	Flow, per cent	Unit Weight, lb. per cu. ft.	Compressive Strength, psi.				
Cement	Filler[a]					1 day	3 days	7 days	28 days	3 months
				PLAIN CONCRETE—2-IN. SLUMP						
2	..	Moist	2.50	160	142.4	235	560	575	725	685
2½	..		1.88	154	143.5	390	925	1110	1205	1225
3	..		1.51	150	145.2	665	1480	1825	1850	1945
3½	..		1.30	152	146.7	935	1980	2405	2780	2615
4	..		1.13	157	147.5	1340	2775	3395	3675	3600
5	..		0.88	150	149.8	2205	3915	4750	5200	5140
6	..		0.72	141	150.6	3170	4980	5670	6255	6460
2	..	3 days moist then air	2.50	160	142.4	235	490	685	975	995
2½	..		1.88	154	143.5	390	905	1220	1585	1445
3	..		1.51	150	145.2	665	1495	2025	2475	2170
3½	..		1.30	152	146.7	935	1775	2745	3140	2775
4	..		1.13	157	147.5	1340	2715	3435	4120	3750
5	..		0.88	150	149.8	2205	3935	4935	5385	5280
6	..		0.72	141	150.6	3170	4860	6095	6425	6400
2	..	1 day moist then air	2.50	160	142.4	235	560	715	835	775
2½	..		1.88	154	143.5	390	940	1265	1405	1420
3	..		1.51	150	145.2	665	1505	1785	2045	1995
3½	..		1.30	152	146.7	935	1995	2420	2745	2485
4	..		1.13	157	147.5	1340	2730	3265	3570	3570
5	..		0.88	150	149.8	2205	3975	4695	4970	4780
6	..		0.72	141	150.6	3170	4945	5885	6375	6220
				CONCRETE WITH FILLER—2-IN. SLUMP						
2	3	Moist	2.43	155	146.4	455	870	1015	1100	1180
2½	2½		1.92	153	146.8	735	1215	1465	1715	1805
3	2		1.57	154	147.6	1055	1940	2290	2615	2455
3½	1½		1.33	151	148.1	1280	2525	3105	3215	3495
4	1		1.15	151	148.8	1550	3215	3705	4385	4325
5	1		0.94	149	149.2	2495	4375	4655	5235	5975
2	3	3 days moist then air	2.43	155	146.4	455	825	1180	1465	1810
2½	2½		1.92	153	146.8	735	1360	1850	2235	2550
3	2		1.57	154	147.6	1055	1935	2475	3000	2935
3½	1½		1.33	151	148.1	1280	2755	3355	4125	3985
4	1		1.15	151	148.8	1550	3215	4335	5010	4535
5	1		0.94	149	149.2	2495	4545	5445	6120	5770
2	3	1 day moist then air	2.43	155	146.4	455	855	1090	1290	1445
2½	2½		1.92	153	146.8	735	1380	1715	2040	2235
3	2		1.57	154	147.6	1055	2040	2315	2755	2755
3½	1½		1.33	151	148.1	1280	2590	3170	3445	3420
4	1		1.15	151	148.8	1550	3215	3745	4185	3930
5	1		0.94	149	149.2	2495	4275	4795	5275	4945
				PLAIN CONCRETE—6-IN. SLUMP						
3½	..	Moist	1.45	195	146.3	715	1700	1905	2285	2235
4	..		1.27	196	147.6	1010	2205	2530	2825	2865
5	..		0.94	178	149.6	1870	3695	4150	4630	4605
6	..		0.80	164	150.5	2530	4010	4860	5830	6315
3½	..	3 days moist then air	1.45	195	146.3	715	1665	2195	2725	2510
4	..		1.27	196	147.6	1010	2160	2840	3430	3225
5	..		0.94	178	149.6	1870	3635	4475	4835	4665
6	..		0.80	164	150.5	2530	4275	5165	5655	5770
3½	..	1 day moist then air	1.45	195	146.3	715	1595	1960	2275	2085
4	..		1.27	196	147.6	1010	2130	2655	2960	2825
5	..		0.94	178	149.6	1870	3640	4250	4360	4460
6	..		0.80	164	150.5	2530	4155	4720	5345	5030
				CONCRETE WITH FILLER—6-IN. SLUMP						
2	3	Moist	2.80	184	146.3	320	555	705	765	900
2½	2½		2.17	178	146.6	460	950	1225	1315	1405
3	2		1.78	178	146.9	685	1495	1745	1855	1980
3½	1½		1.46	173	147.4	880	2095	2480	2825	2895
4	1		1.31	181	148.2	1095	2465	2830	3275	3120
5	1		1.05	171	148.9	1765	3435	3785	4220	4635
2	3	3 days moist then air	2.80	184	146.3	320	595	810	1055	1145
2½	2½		2.17	178	146.6	460	965	1365	1745	1860
3	2		1.78	178	146.9	685	1415	2035	2405	2500
3½	1½		1.46	173	147.4	880	2045	2675	3060	3065
4	1		1.31	181	148.2	1095	2450	3075	3500	3540
5	1		1.05	171	148.9	1765	3645	4155	5145	4505
2	3	1 day moist then air	2.80	184	146.3	320	625	765	965	1045
2½	2½		2.17	178	146.6	460	980	1235	1465	1650
3	2		1.78	178	146.9	685	1410	1765	2115	2055
3½	1½		1.46	173	147.4	880	1985	2565	2895	2860
4	1		1.31	181	148.2	1095	2370	2910	3130	3135
5	1		1.05	171	148.9	1765	3430	4000	4370	4315

[a] 1 bag of filler (80.8 lb.) is equal by absolute volume to 1 bag of cement.

[b] Water-cement ratio based on cement only.

Volume Change:

Stainless steel pins in the ends of the 3 by 3 by 12-in. concrete beams were used as reference points. Measurements were made beginning at 24 hr. with a 300-mm. micrometer. All observations were with the concrete at 70 F.

DISCUSSION OF TESTS

The investigation covered typical gravel concrete graded to 1½ in. as representing average job conditions. A 2-in. slump was selected as representing

TABLE VII.—VOLUME CHANGE TESTS.

Tests of 3 by 3 by 12-in. concrete beams.
Length changes after 3 month storage average of 3 tests.

Nominal Mix, bags per cu. yd.		Length Changes, per cent of 24-hr. length									
		Portland Cement						High-Early-Strength Cement			
		1745 sq. cm. per g.		2160 sq. cm. per g.		2520 sq. cm. per g.		2440 sq. cm. per g.		2665 sq. cm. per g.	
Cement	Filler[a]	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump
STORED 1 DAY IN MOLD THEN IN WATER OF 70 F.											
2	0	+0.007	....	−0.001	....	+0.006	....	0	....	−0.001	....
2	3	+0.001	+0.004	−0.004	−0.005	−0.006	+0.003	−0.002	−0.001	−0.002	0
2½	0	+0.005	....	+0.002	....	+0.003	....	−0.004	....	−0.003	....
2½	2½	−0.004	+0.007	−0.005	−0.001	−0.004	−0.002	−0.006	−0.003	−0.003	0
3	0	−0.001	....	+0.003	....	+0.002	....	−0.001	....	−0.002	....
3	2	−0.003	+0.004	−0.007	−0.007	−0.007	−0.008	−0.003	−0.003	−0.004	−0.001
3½	0	−0.006	+0.008	−0.003	+0.001	−0.001	−0.003	−0.003	−0.001	−0.003	−0.002
3½	1½	−0.006	−0.001	−0.008	−0.007	−0.008	−0.007	−0.003	−0.001	−0.004	−0.001
4	0	−0.003	+0.003	−0.003	+0.002	+0.001	−0.003	−0.002	0	−0.002	−0.003
4	1	−0.006	+0.002	−0.11	0	−0.001	−0.006	−0.002	−0.003	−0.006	−0.003
5	0	−0.002	+0.006	−0.006	+0.003	+0.001	−0.004	−0.001	0	−0.002	−0.002
5	1	−0.006	0	−0.007	−0.005	+0.001	−0.007	−0.001	−0.004	−0.006	−0.003
6	0	−0.003	+0.006	−0.005	+0.005	0	−0.003	+0.001	−0.002	−0.001	−0.002
STORED 1 DAY IN MOLD THEN AIR OF 50 TO 55 PER CENT RELATIVE HUMIDITY											
2	0	−0.048	....	−0.045	....	−0.046	....	−0.035	....	−0.037	....
2	3	....	−0.064	−0.073	−0.081	−0.066	−0.084	−0.061	−0.062	−0.069	−0.071
2½	0	−0.052	....	−0.034	....	−0.034	....	−0.037	....	−0.039	....
2½	2½	−0.052	−0.060	−0.061	−0.074	−0.067	−0.066	−0.064	−0.062	−0.065	−0.063
3	0	−0.037	....	−0.044	....	−0.043	....	−0.047	....	−0.046	....
3	2	−0.053	−0.055	−0.059	−0.068	−0.060	−0.059	−0.064	−0.053	−0.060	−0.064
3½	0	−0.054	−0.037	−0.046	−0.039	−0.043	−0.045	−0.049	−0.051	−0.044	−0.051
3½	1½	−0.046	−0.051	−0.056	−0.064	−0.061	−0.067	−0.059	−0.058	−0.061	−0.061
4	0	−0.041	−0.048	−0.041	−0.038	−0.041	−0.054	−0.045	−0.046	−0.046	−0.051
4	1	−0.045	−0.046	−0.054	−0.058	−0.050	−0.057	−0.054	−0.059	−0.058	−0.058
5	0	−0.047	−0.038	−0.045	−0.041	−0.043	−0.046	−0.050	−0.049	−0.048	−0.050
5	1	−0.053	−0.057	−0.056	−0.053	−0.051	−0.062	−0.063	−0.059	−0.058	−0.062
6	0	−0.046	−0.037	−0.043	−0.039	−0.043	−0.051	−0.047	−0.049	−0.048	−0.052
STORED 1 DAY IN MOLD, 6 DAYS WATER THEN AIR OF 50 TO 55 PER CENT RELATIVE HUMIDITY											
2	0	−0.053	....	....	....	−0.036	....	−0.038	....	−0.033	....
2	3	−0.058	−0.059	−0.066	−0.073	−0.071	−0.090	−0.069	−0.069	−0.072	−0.075
2½	0	−0.040	....	−0.031	....	−0.038	....	−0.033	....	−0.042	....
2½	2½	−0.058	−0.060	−0.070	−0.066	−0.069	−0.072	−0.068	−0.061	−0.064	−0.070
3	0	−0.039	....	−0.037	....	−0.038	....	−0.050	....	−0.049	....
3	2	−0.050	−0.060	−0.067	−0.067	−0.066	−0.064	−0.060	−0.064	−0.059	−0.068
3½	0	−0.039	−0.035	−0.040	−0.037	−0.051	−0.048	−0.052	−0.057	−0.048	−0.054
3½	1½	−0.054	−0.055	−0.060	−0.056	−0.061	−0.059	−0.060	−0.061	−0.059	−0.066
4	0	−0.040	−0.039	−0.044	−0.042	−0.043	−0.053	−0.049	−0.056	−0.049	−0.055
4	1	−0.050	−0.045	−0.056	−0.058	−0.049	−0.058	−0.056	−0.060	−0.055	−0.057
5	0	−0.044	−0.044	−0.043	−0.046	−0.052	−0.052	−0.050	−0.048	−0.046	−0.049
5	1	−0.050	−0.048	−0.056	−0.052	−0.055	−0.062	−0.054	−0.059	−0.057	−0.062
6	0	−0.047	−0.043	−0.047	−0.040	−0.045	−0.050	−0.045	−0.048	−0.040	−0.049

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[a] 1 bag filler (80.8 lb.) is equal by absolute volume to 1 bag cement.

TABLE VII—*Continued.*

Nominal Mix, bags per cu. yd.		Length Changes, per cent of 24-hr. length									
		Portland Cement						High-Early-Strength Cement			
Cement	Filler[a]	1745 sq. cm. per g.		2160 sq. cm. per g.		2520 sq. cm. per g.		2440 sq. cm. per g.		2665 sq. cm. per g.	
		2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump
STORED 1 DAY IN MOLD, 13 DAYS IN WATER; THEN ALTERNATE AIR AND WATER EVERY 15 DAYS											
2	0	−0.024	....	−0.035	....	−0.030	....	−0.027	....	−0.033	....
2	3	−0.038	−0.054	−0.042	−0.039	−0.043	−0.047	−0.038	−0.047	−0.039	−0.048
2½	0	−0.019	....	−0.020	....	−0.023	....	−0.034	....	−0.037	....
2½	2½	−0.018	−0.032	−0.038	−0.031	−0.040	−0.043	−0.043	−0.043	−0.042	−0.038
3	0	−0.023	....	−0.025	....	−0.030	....	−0.035	....	−0.039	....
3	2	−0.026	−0.030	−0.033	−0.034	−0.036	−0.037	−0.042	−0.039	−0.038	−0.040
3½	0	−0.024	−0.017	−0.028	−0.023	−0.037	−0.033	−0.034	−0.035	−0.034	−0.037
3½	1½	−0.027	−0.025	−0.033	−0.031	−0.032	−0.033	−0.043	−0.036	−0.043	−0.039
4	0	−0.034	−0.023	−0.030	−0.021	−0.029	−0.037	−0.033	−0.037	−0.034	−0.040
4	1	−0.026	−0.024	−0.028	−0.026	−0.030	−0.030	−0.037	−0.037	−0.040	−0.038
5	0	−0.024	−0.024	−0.027	−0.025	−0.030	−0.035	−0.029	−0.030	−0.037	−0.036
5	1	−0.025	−0.029	−0.031	−0.026	−0.030	−0.034	−0.034	−0.040	−0.036	−0.038
6	0	−0.023	−0.025	−0.024	−0.019	−0.026	−0.028	−0.030	−0.029	−0.025	−0.032

road mixes and a 6-in. slump for structural concrete.

Optimum sand contents as determined by the preliminary tests of the various mixes were:

Cement, bags per cu. yd.	Sand, per cent by weight of total aggregate
2	44.5
3	42.2
4	39.7
5	36.4
6	34.0

In the leaner mixes, a further increase in sand was of no benefit.

For identical slumps, workability improved as the cement content increased; cohesiveness increased and the mixes became more plastic and easier to mold. The wide range of mixes used indicated the limitations of the slump test as a measure of workability.

Flow tests were also made on all batches. As cement content increased from 2 to 6 bags, flow decreased by about 9 per cent for 2-in. slump and by 13 per cent for 6-in. slump concretes. In 6-in. slump mixes, there was a critical cement content of about 3½ bags below which it was impossible to produce this slump, although the mixes were saturated with water. The finer cements improved the workability, but in all mixes below 3½ bags cement, the increase in fineness did not offset the lack of plastic material necessary for effective lubrication of aggregates. From the standpoint of workability alone, cement could be replaced by any material of equal or greater fineness. In these tests the pulverized limestone filler had about 52 per cent of material finer than 7½ μ, and was an effective plasticizer.

In general, the quantity of mixing water per cubic yard of concrete for a given slump decreased as cement content increased as shown in Table A (p. 822). It is to be observed, however, that for conventional mixes of 5 and 6 bags, the water requirements per unit of volume of concrete were about the same, as has been pointed out by other investigators.

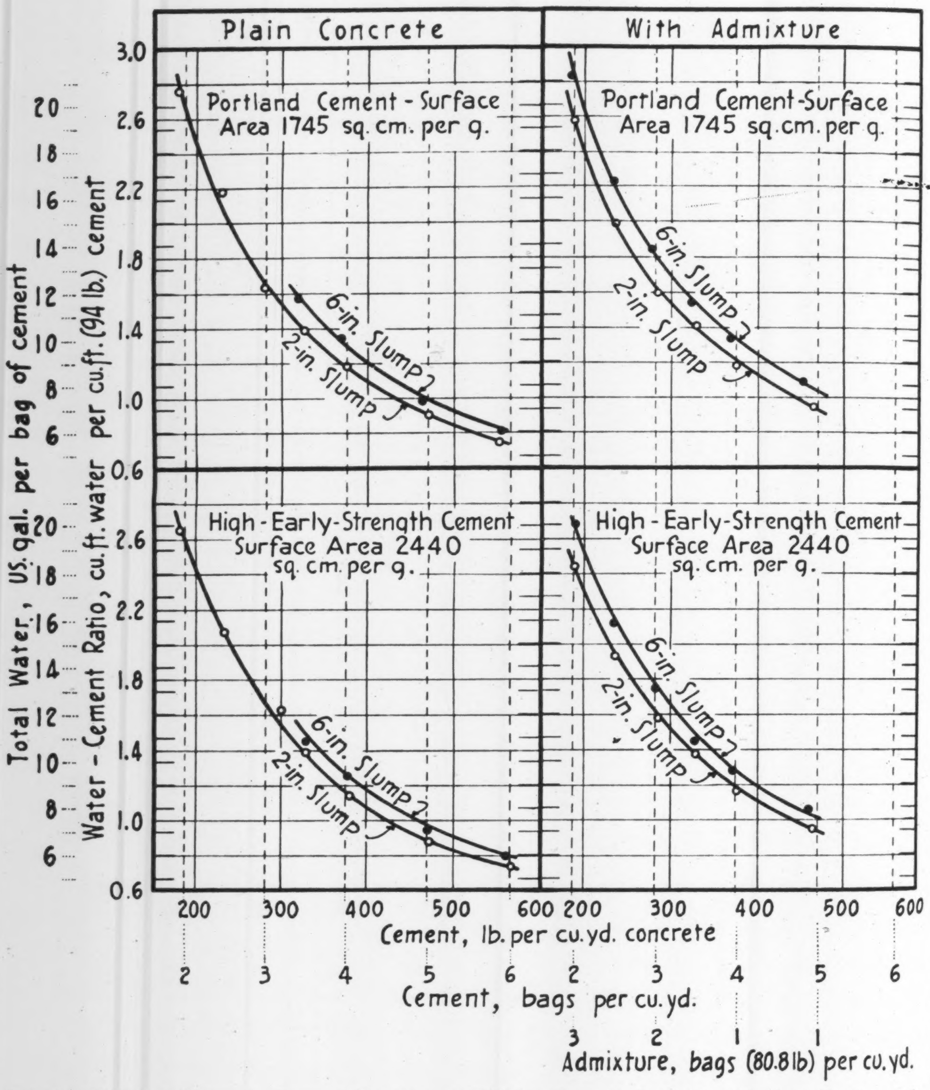

FIG. 1.—Relation Between Cement Content and Water-Cement Ratio Required to Produce 2-in. and 6-in. Slump Concrete.

Sand and gravel aggregate graded from 0 to 1½ in.
Admixture: pulverized limestone—Surface area 3450 sq. cm. per g., specific gravity 2.71.
Each point is average of 9 slump tests determined on 9 different batches.

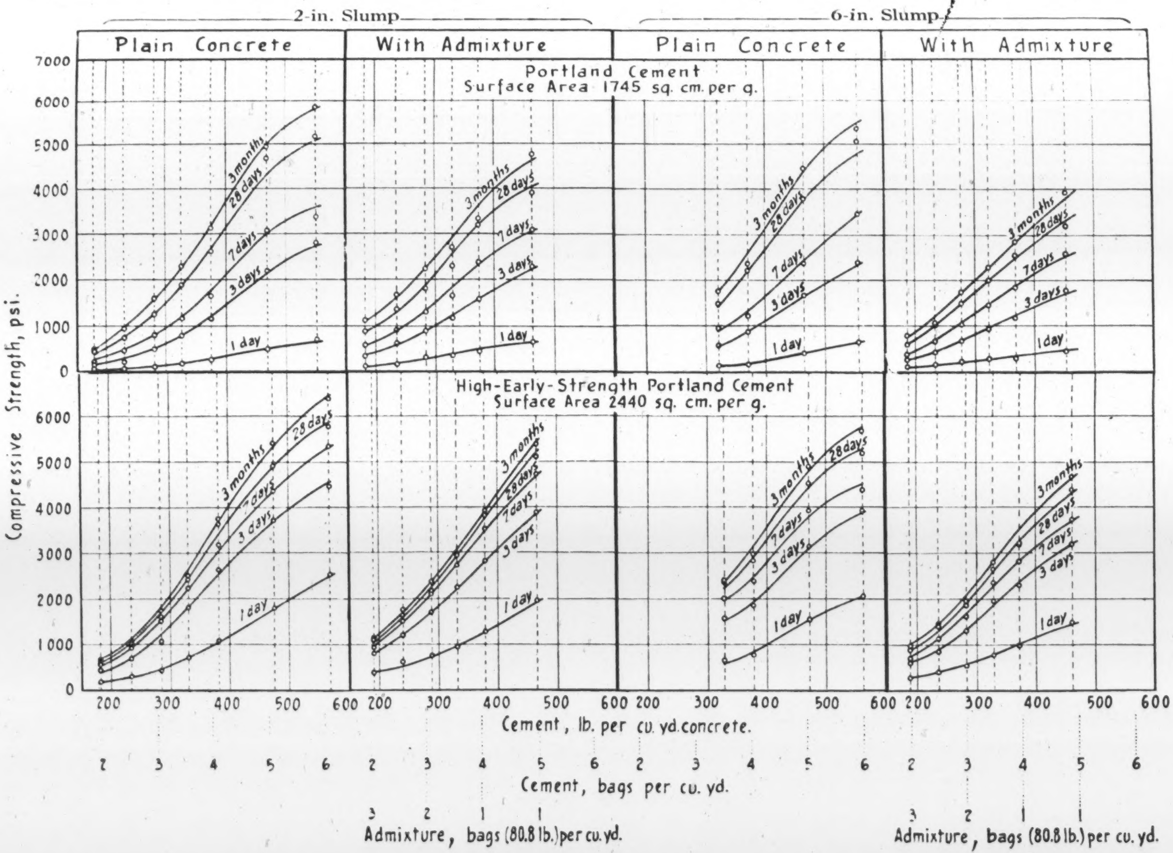

FIG. 2.—Cement Content – Strength Relation.

2- and 6-in. slump concrete, cured moist at 70 F.
Compression tests of 6 by 12-in. cylinders.
Admixture: pulverized limestone, surface area 3450 sq. cm. per g., specific gravity 2.71.

TABLE A.

	Specific Surface, sq. cm. per g.	Water per cu. yd. of concrete, lb.										
		2-in. Slump							6-in. Slump			
		2 bags of Cement per cu.yd.	2½ bags of Cement per cu.yd.	3 bags of Cement per cu.yd.	3½ bags of Cement per cu.yd.	4 bags of Cement per cu.yd.	5 bags of Cement per cu.yd.	6 bags of Cement per cu.yd.	3½ bags of Cement per cu.yd.	4 bags of Cement per cu.yd.	5 bags of Cement per cu.yd.	6 bags of Cement per cu.yd.
Portland cement	1745	330	333	304	301	294	281	282	335	328	303	299
	2160	318	319	316	305	290	275	278	309	309	296	299
	2520	336	326	308	298	283	271	271	314	310	288	288
High-early-strength cement	2440	321	321	307	303	289	278	280	317	313	296	300
	2655	304	293	286	287	285	277	272	316	319	296	298

In general, the finer cements required less water for the same slump.

Cement content and water-cement ratio for a given slump were intimately related. Figure 1 shows this relation for two of the cements—plain concrete and with filler. For the mixes with filler, the water-cement ratio is based on cement content only and not corrected for absorption. In mixes below 3 bags, the concrete with filler required slightly less water than the plain concrete, in richer mixes, more water.

STRENGTH TESTS

Effect of Cement Content on Strength:

Strength data are given in Tables II to VI inclusive. The typical relation between cement content and compressive strength of moist-cured concrete, plain and with filler, is plotted for 2 cements in Fig. 2. Table VIII gives the average strength percentages in relation to a 5-bag mix.

Strengths decreased as cement content was reduced. The rate of strength decrease changes at a cement content between 5½ and 6 bags. The decrease in strength from a 5 to 4-bag mix was about

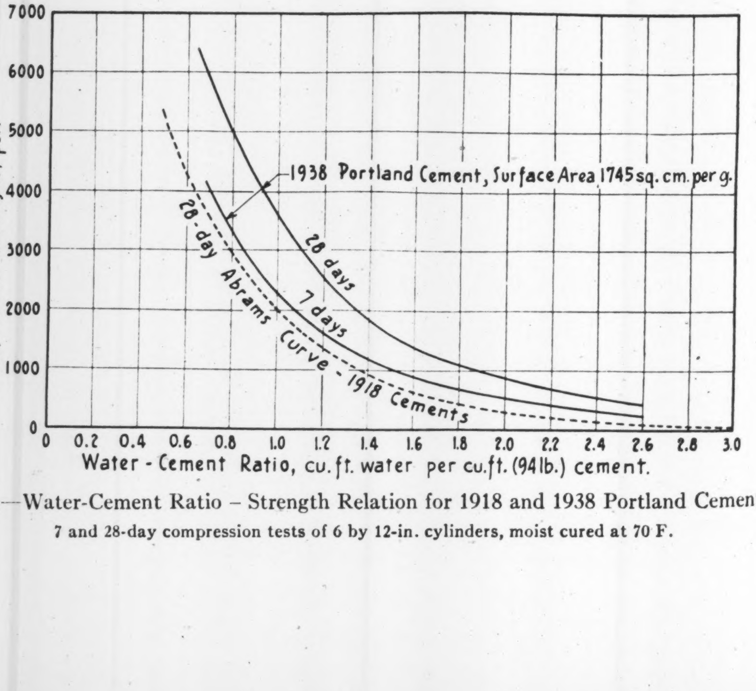

FIG. 3.—Water-Cement Ratio – Strength Relation for 1918 and 1938 Portland Cements.
7 and 28-day compression tests of 6 by 12-in. cylinders, moist cured at 70 F.

twice as great as that from a 6 to a 5-bag mix. Below are the decreases in 28-day strength as indicated by the cement-strength curves.

The greater decrease in strength in mixes below 5 bags is of much practical importance; it means that the leaner mixes are more sensitive to changes in

DECREASE OF 28-DAY STRENGTH FOR REDUCTION IN CEMENT CONTENT, PSI.

Reduction in Cement Content	Portland Cement						High-Early-Strength Portland Cement			
	1745 sq. cm. per g.		2160 sq. cm. per g.		2520 sq. cm. per g.		2440 sq. cm. per g.		2655 sq. cm. per g.	
	2-in. Slump	6-in Slump	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump	2-in. Slump	6-in. Slump
6 to 5 Bags	830	1010	800	840	820	750	990	900	1200	1320
5 to 4 Bags	1650	1570	1850	1620	1630	1710	1560	1500	1540	1700
4 to 3 Bags	1420	....	1750	....	1970	....	1640	....	1640	....
3 to 2 Bags	800	....	870	....	860	....	1010	....	1090	...

TABLE VIII.—EFFECT OF CEMENT CONTENT ON COMPRESSIVE STRENGTH OF MOIST CURED CONCRETE.

Strength expressed as percentage of strength of 5-bag plain concrete mix.
Strength ratios are calculated from curves as in Fig. 2.

Plain Concrete						With Filler						
Mix	Percent of Strength of 5-bag Plain Concrete Mix					Mix		Percent of Strength of 5-bag Plain Concrete Mix				
Cement, bags per cu. yd.	1 day	3 days	7 days	28 days	3 months	Cement, bags per cu. yd.	Filler, bags per cu. yd.[a]	1 day	3 days	7 days	28 days	3 months
2-IN. SLUMP												
PORTLAND CEMENT—SURFACE AREA 1745 SQ. CM. PER G.												
2	10	8	10	10	11	2	3	22	18	20	21	23
3	25	23	27	29	31	3	2	51	40	43	42	44
4	57	56	59	62	64	4	1	98	74	77	74	72
5	100	100	100	100	100	5	1	127	105	103	94	93
6	131	129	121	119	117							
PORTLAND CEMENT—SURFACE AREA 2160 SQ. CM. PER G.												
2	8	11	11	11	11	2	3	21	19	17	18	18
3	24	26	27	29	30	3	2	48	45	44	42	44
4	52	61	62	64	65	4	1	87	81	77	72	71
5	100	100	100	100	100	5	1	121	111	98	90	89
6	148	129	125	116	118							
PORTLAND CEMENT—SURFACE AREA 2520 SQ. CM. PER G.												
2	6	9	10	10	11	2	3	24	16	16	18	20
3	17	23	26	28	29	3	2	46	41	44	45	44
4	52	59	63	67	68	4	1	81	74	76	77	78
5	100	100	100	100	100	5	1	138	102	104	101	103
6	158	123	120	116	118							
HIGH-EARLY-STRENGTH CEMENT—SURFACE AREA 2440 SQ. CM. PER G.												
2	10	11	13	13	14	2	3	23	22	22	21	21
3	27	33	35	34	34	3	2	40	46	47	44	43
4	58	67	68	68	68	4	1	72	76	79	73	72
5	100	100	100	100	100	5	1	113	108	111	108	104
6	143	125	123	120	122							
HIGH-EARLY-STRENGTH CEMENT—SURFACE AREA 2655 SQ. CM. PER G.												
2	12	14	14	15	16	2	3	21	21	23	22	23
3	30	35	36	36	37	3	2	45	48	48	47	49
4	60	67	68	69	70	4	1	75	84	80	81	85
5	100	100	100	100	100	5	1	118	111	103	108	115
6	143	126	124	124	125							

Plain Concrete						With Filler						
Mix	Percent of Strength of 5-bag Plain Concrete Mix					Mix		Percent of Strength of 5-bag Plain Concrete Mix				
Cement, bags per cu. yd.	1 day	3 days	7 days	28 days	3 months	Cement, bags per cu. yd.	Filler, bags per cu. yd.[a]	1 day	3 days	7 days	28 days	3 months
6-IN. SLUMP												
PORTLAND CEMENT—SURFACE AREA 1745 SQ. CM. PER G.												
3½	31	36	38	41	43	2	3	24	15	15	16	17
4	48	55	55	59	60	3	2	50	42	44	39	39
5	100	100	100	100	100	4	1	86	76	76	65	64
6	157	143	140	126	124	5	1	119	106	105	90	89
PORTLAND CEMENT—SURFACE AREA 2160 SQ. CM. PER G.												
3½	47	42	41	43	46	2	3	31	16	16	16	18
4	58	60	59	63	64	3	2	58	39	39	38	41
5	100	100	100	100	100	4	1	93	72	71	68	68
6	122	134	129	119	118	5	1	133	103	104	95	94
PORTLAND CEMENT—SURFACE AREA 2520 SQ. CM. PER G.												
3½	31	37	41	46	48	2	3	23	16	19	19	19
4	50	54	53	63	64	3	2	50	39	40	40	42
5	100	100	100	100	100	4	1	93	70	71	68	68
6	146	123	122	116	115	5	1	129	97	96	91	88
HIGH-EARLY-STRENGTH PORTLAND CEMENT—SURFACE AREA 2440 SQ. CM. PER G.												
3½	38	50	52	51	50	2	3	18	20	20	20	21
4	54	62	65	66	65	3	2	39	43	45	43	43
5	100	100	100	100	100	4	1	68	79	76	75	75
6	134	127	120	120	121	5	1	97	107	101	100	99
HIGH-EARLY-STRENGTH PORTLAND CEMENT—SURFACE AREA 2655 SQ. CM. PER G.												
3½	40	52	48	47	48	2	3	19	17	18	18	19
4	58	67	64	62	62	3	2	35	44	43	42	43
5	100	100	100	100	100	4	1	64	76	75	74	76
6	134	121	121	129	132	5	1	96	99	96	97	100

[a] 1 bag of filler (80.8 lb.) is equal by absolute volume to 1 bag cement.

cement content and that such mixes require very careful control of quantities to assure consistent results in the field.

Figure 3 compares water-ratio - strength curves of a modern cement with the 1918 cements used by Abrams.[4] To produce 2000-psi. 28-day concrete, a water-cement ratio of 1.0 is indicated for 1918 cements. A modern portland cement produces the same strength with a water-cement ratio of 1.35. The 1918 water-cement ratio required about 4½ to 5 bags per cu. yd., or 1 bag more than is required with present-day cements. Modern 7-day strengths are higher than the 28-day strengths in 1918. Thus, from the standpoint of strength alone, and ignoring durability, the modern cements permit a great reduction in cement content as compared to the cements of 20 yr. ago.

Water-cement ratio – strength curves for the portland cements used in these tests are shown in Fig. 4. These curves are similar to those of Abrams, but show greater strengths at all ages.

Effect of Cement Fineness on Strength:

Increase in cement fineness improved compressive strength at all ages. However, the effect of fineness was greater at ages up to 7 days than at later periods. The table below gives percentages of increase for portland cement, based on tangents drawn to curves at 2100 specific surface (Fig. 5).

PERCENTAGE STRENGTH INCREASE PER 100 SQ. CM. INCREASE IN SPECIFIC SURFACE.

Age	2-in. Slump				6-in. Slump			
	3½ bags cement per cu. yd.	4 bags cement per cu. yd.	5 bags cement per cu. yd.	6 bags cement per cu. yd.	3½ bags cement per cu. yd.	4 bags cement per cu. yd.	5 bags cement per cu. yd.	6 bags cement per cu. yd.
1 day	4.6	6.3	8.9	10.3	8.3	7.6	7.6	7.7
3 days	2.1	5.8	4.5	4.4	7.0	6.4	6.7	4.5
7 days	4.5	5.0	3.6	4.1	5.0	5.2	4.7	2.6
28 days	2.3	3.3	1.8	1.7	4.5	3.5	2.9	0.9
3 months	1.2	2.4	1.5	1.3	1.6	3.2	2.0	0.9

Strengths of the high-early-strength cement were similarly improved by increasing fineness. At 24 hr. the high-early-strength cement had twice the strength of the portland cement of the same fineness, indicating that fineness is only one of the factors responsible for the high-early-strength qualities.

Effect of Filler on Strength:

Typical strength and water-cement ratio curves for mixes with filler are plotted in Figs. 1, 2, and 4. The addition of filler to the mixes containing 2 to 4 bags of cement increased the compressive strength. Strengths at 28 days and 3 months of the 5-bag mixes were generally reduced by addition of filler.

When the filler is used as a third aggregate, it improves the strength of those mixes which have insufficient fine material to make plastic concrete. Since the filler was chemically inert, this strength increase must be due to improvement of the physical characteristics of the mix. The effectiveness of the filler decreased as cement content increased until the filler became harmful in mixes richer than 5 bags. This has been previously indicated by Abrams[5] who studied the effect of various admixtures in concrete with 6 bags of cement per cubic yard.

When the filler is considered as a substitute for cement, it reduces the strength in proportion to the amount of cement it replaces. Figure 6 shows the strengths of portland-cement concrete in which cement was replaced by an equal absolute volume of filler. In general these results are similar to those described by McMillan and Powers.[6]

The following table gives comparative amounts of cement and com-

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[4] D. A. Abrams, "Design of Concrete Mixtures," *Bulletin 1*, Lewis Inst., Chicago, Ill. (1918).

[5] D. A. Abrams, "Tests of Powdered Admixtures in Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 29, Part II, p. 618 (1929).

[6] F. R. McMillan and T. C. Powers, "A Method of Evaluating Admixtures," *Proceedings*, Am. Concrete Inst., Vol. 30, p. 325 (1934).

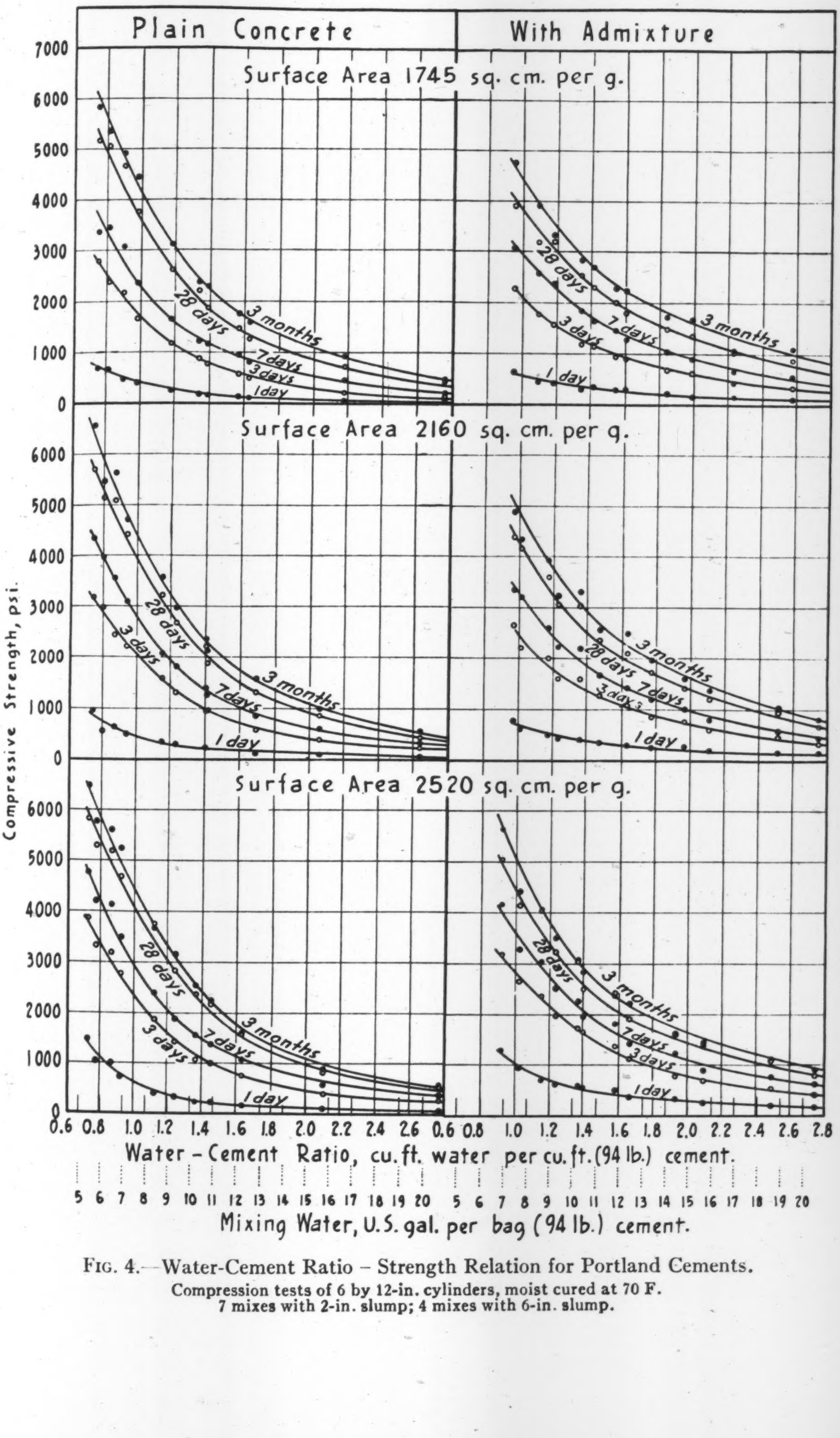

FIG. 4.—Water-Cement Ratio – Strength Relation for Portland Cements.

Compression tests of 6 by 12-in. cylinders, moist cured at 70 F.
7 mixes with 2-in. slump; 4 mixes with 6-in. slump.

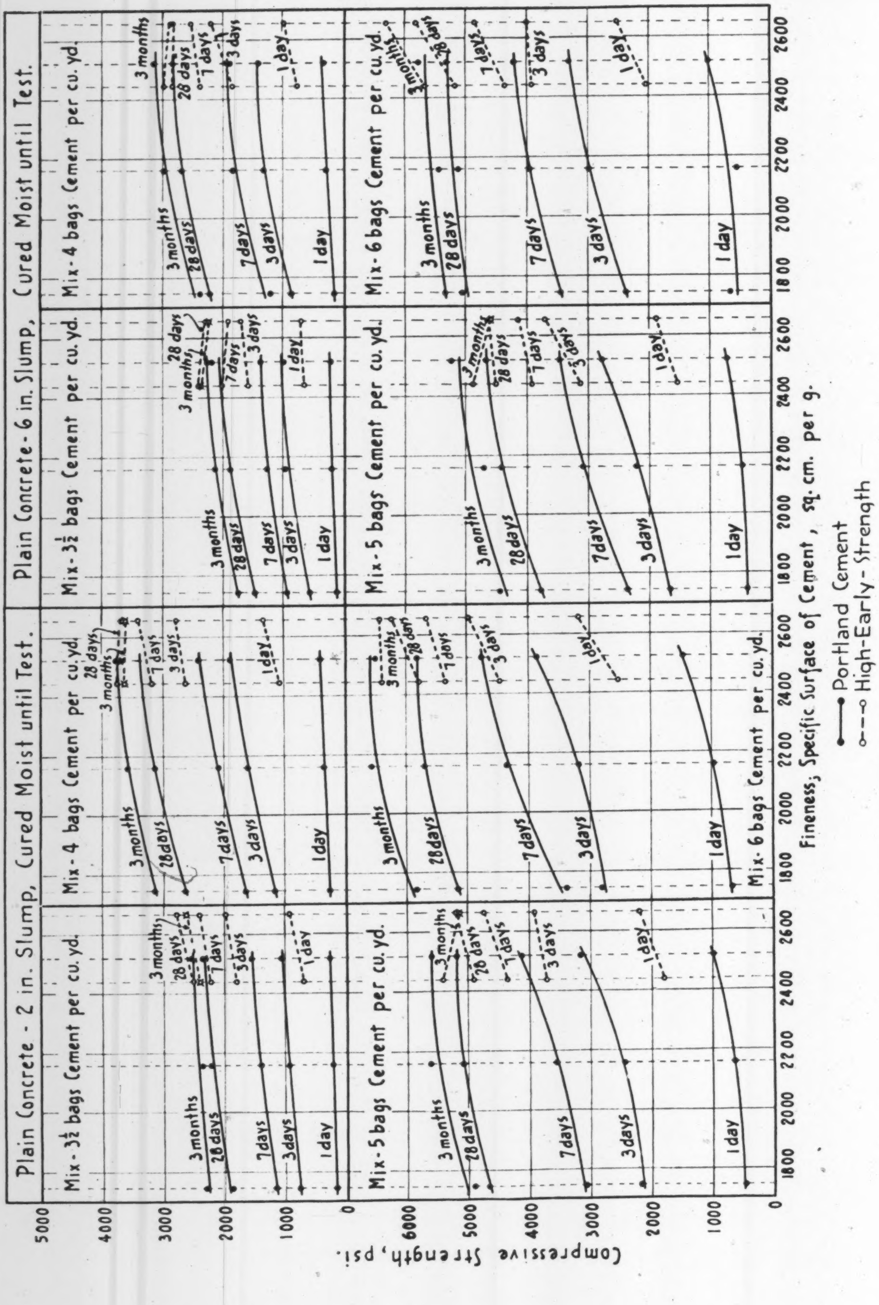

FIG. 5.—Effect of Cement Fineness on Compressive Strength.

Solid lines = portland cement.
Dash lines = high-early-strength cement.
Compression tests of 6 by 12-in. cylinders.

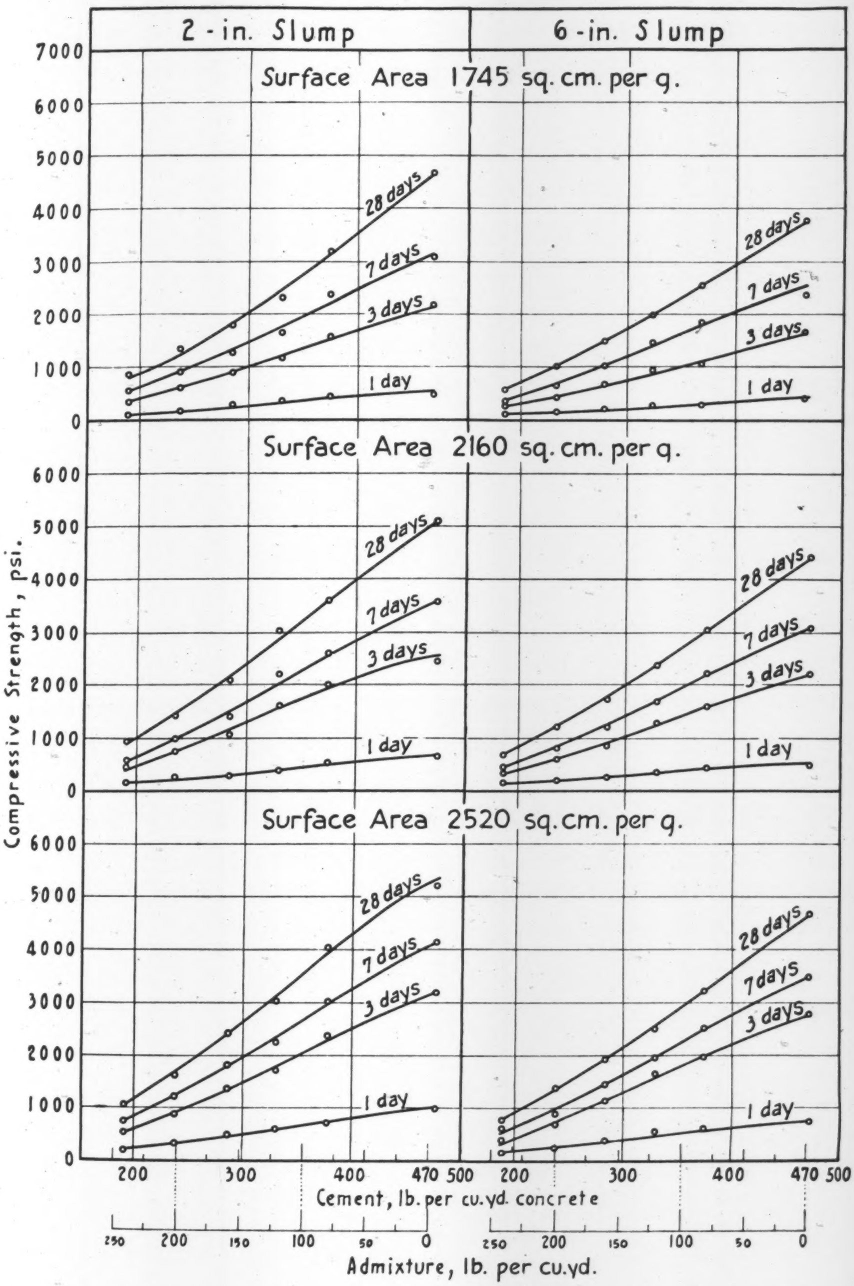

FIG. 6.—Effect of Admixture on Strength, When Replacing Portland Cement in a 5-bag Mix.
Compression tests of 6 by 12-in. cylinders, moist cured at 70 F.

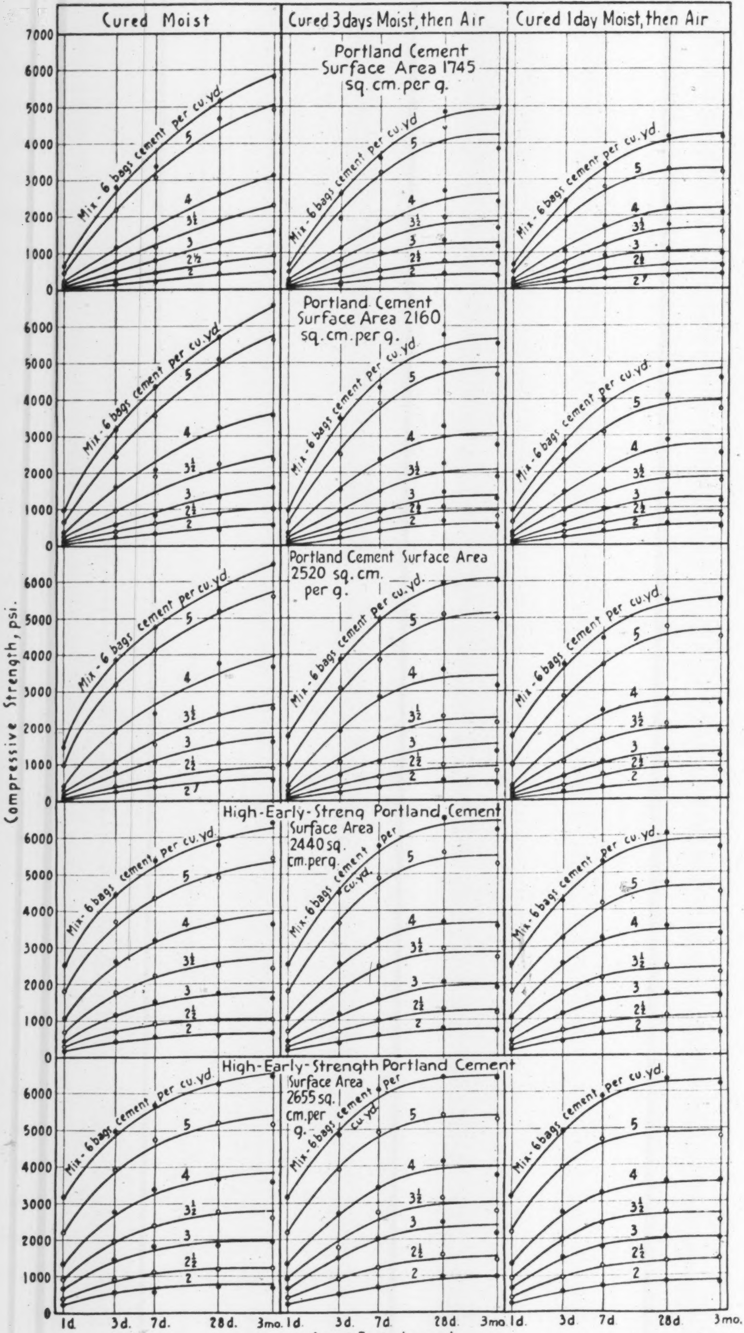

FIG. 7.—Age-Strength Relation for Plain Concrete and 3 Curing Conditions, 2-in. Slump.

Compression tests of 6 by 12-in. cylinders.
Cylinders tested as cured.

bined cement and filler required for a given 28-day strength, with 2-in. slump:

Type of Cement	Surface Area, sq. cm. per g.	Plain Concrete Cement, lb.	With Filler		Ratio of Filler to Cement Replaced
			Cement, lb.	Filler, lb.	
2500-LB. CONCRETE					
Portland cement	1745	365	325	125	3.1
High-early-strength cement	2440	335	305	142	4.7
3000-LB. CONCRETE					
Portland cement	1745	390	360	95	3.1
High-early-strength cement	2440	360	335	116	4.65
3500-LB. CONCRETE					
Portland cement	1745	420	400	60	3.0
High-early-strength cement	2440	390	365	82	3.3

The data show the cement to be 3 to 4.5 times more effective in improving strengths than an equal amount of filler.

Effect of Curing on Compressive Strength:

Age-strength curves for all cements and mixes of plain 2-in. slump concrete are shown in Fig. 7. All specimens were tested as cured.

All moist-cured specimens gained steadily in strength. The rate of strength gain was greater for the richer mixes. Air-cured specimens gained practically no strength after 28 days; in a number of cases their 3-month strengths were lower than at 28 days. In addition, they had lower strengths at 3 months than the corresponding moist-cured specimens. Similar observations have been previously reported.[7]

As cement fineness increased, the difference in strength due to air curing diminished and was least with the high-early-strength cements. The finer cements and particularly the high-early-strength cements hydrate at a more rapid rate and make more effective use of 1 and 3-day moist curing.

Air-cured mixes with filler generally showed smaller difference in strength at 3 months than the plain mixes. The effect of air curing on strength is given below for the 2-in. slump concrete. Values in the table are calculated from the curves in Fig. 7. Results for 6-in. slump are similar.

3-MONTH AIR-CURED STRENGTHS EXPRESSED AS PERCENTAGE OF 3-MONTH MOIST-CURED STRENGTHS—2-IN. SLUMP.

Mix, bags of cement per cu. yd.		2		3		4		5		6	
Cement	Specific Surface	Moist cured 1 day	Moist cured 3 days	Moist cured 1 day	Moist cured 3 days	Moist cured 1 day	Moist cured 3 days	Moist cured 1 day	Moist cured 3 days	Moist cured 1 day	Moist cured 3 days
PLAIN CONCRETE											
Portland	1745	70	72	67	82	69	82	66	85	72	75
	2160	87	95	78	83	77	86	71	88	74	87
	2520	74	85	82	97	74	93	86	95	87	95
High-early-strength	2440	95	100	88	110	98	103	87	103	92	100
	2655	99	118	104	124	102	111	95	104	98	100
CONCRETE WITH FILLER											
Portland	1745	61	85	65	98	69	92	74	94	..	..
	2160	73	96	77	91	73	86	77	87	..	..
	2520	84	106	88	107	78	93	79	92	..	..
High-early-strength	2440	116	132	100	122	94	105	88	96	..	..
	2655	112	140	108	129	93	109	91	101	..	..

The above results indicate the high-early-strength cement to be the more effective from the standpoint of rapid curing.

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[7] H. F. Gonnerman, "Study of Methods of Curing Concrete," *Proceedings*, Am. Concrete Inst., Vol. 26, p. 359 (1930).

TABLE IX.—RELATIVE DURABILITY OF CONCRETE.

Freezing-and-thawing tests of 6 by 6 by 3-in. concrete blocks, frozen at −20 F., thawed to 70 F.
Number of cycles to produce 25 per cent weight loss, taken from curves as in Fig. 8.
Figures in parentheses denote percentages based on 5-bag plain concrete mix.

Cement	Surface area, sq. cm. per g.	Plain Concrete						With Filler[a]				
		2 bags per cu. yd.	3 bags per cu. yd.	3½ bags per cu. yd.	4 bags per cu. yd.	5 bags per cu. yd.	6 bags per cu. yd.	2 + 3 bags per cu. yd.	3 + 2 bags per cu. yd.	3½ + 1½ bags per cu. yd.	4 + 1 bags per cu. yd.	5 + 1 bags per cu. yd.
2-IN. SLUMP; CURED 1 DAY IN MOLD AND 2 DAYS IN WATER PRIOR TO TEST												
Portland	1745	7 (23)	10 (33)	14 (47)	18 (60)	30 (100)	45 (150)	3 (10)	7 (23)	10 (33)	13 (43)	24 (80)
	2160	9 (28)	13 (41)	17 (53)	20 (62)	32 (100)	47 (147)	6 (19)	8 (25)	10 (31)	13 (40)	22 (69)
	2520	6 (13)	11 (24)	16 (36)	23 (51)	45 (100)	80 (178)	5 (11)	8 (18)	12 (27)	16 (36)	28 (62)
High-early-strength	2440	8 (18)	12 (27)	17 (38)	24 (53)	45 (100)	88 (196)	3 (7)	6 (13)	10 (22)	15 (33)	32 (71)
	2655	11 (19)	19 (33)	25 (44)	34 (60)	57 (100)	94 (165)	4 (7)	11 (19)	16 (28)	23 (40)	41 (72)
2-IN. SLUMP; CURED 1 DAY IN MOLD AND 27 DAYS IN WATER PRIOR TO TEST												
Portland	1745	8 (14)	16 (27)	23 (39)	32 (54)	59 (100)	99 (168)	5 (8)	11 (19)	16 (27)	23 (39)	43 (73)
	2160	7 (11)	18 (30)	27 (44)	36 (49)	61 (100)	96 (157)	3 (5)	9 (15)	15 (25)	22 (36)	41 (67)
	2520	10 (14)	20 (29)	28 (41)	39 (57)	69 (100)	118 (171)	5 (7)	12 (17)	18 (26)	28 (41)	53 (77)
High-early-strength	2440	8 (14)	16 (28)	23 (40)	32 (56)	57 (100)	101 (177)	4 (7)	11 (19)	17 (30)	23 (40)	40 (70)
	2655	8 (13)	19 (31)	26 (43)	34 (56)	61 (100)	119 (195)	4 (7)	12 (20)	17 (28)	25 (41)	47 (77)
6-IN. SLUMP; CURED 1 DAY IN MOLD AND 2 DAYS IN WATER PRIOR TO TEST												
Portland	1745	....	....	8 (40)	11 (55)	20 (100)	31 (155)	1 (5)	3 (15)	5 (25)	8 (40)	16 (80)
	2160	....	....	13 (46)	17 (61)	28 (100)	42 (150)	4 (14)	6 (21)	8 (29)	11 (39)	19 (68)
	2520	....	....	13 (38)	18 (53)	34 (100)	58 (170)	4 (12)	6 (18)	9 (26)	12 (35)	22 (65)
High-early-strength	2440	....	....	12 (35)	17 (50)	34 (100)	57 (168)	3 (9)	6 (18)	9 (26)	13 (38)	23 (68)
	2655	....	....	14 (42)	18 (55)	33 (100)	54 (164)	2 (6)	6 (18)	9 (27)	13 (39)	24 (73)
6-IN. SLUMP; CURED 1 DAY IN MOLD AND 27 DAYS IN WATER PRIOR TO TEST												
Portland	1745	....	....	17 (36)	25 (53)	47 (100)	78 (166)	1 (2)	7 (15)	11 (23)	17 (36)	31 (66)
	2160	....	....	22 (50)	28 (64)	44 (100)	67 (152)	2 (5)	7 (16)	12 (27)	18 (41)	33 (75)
	2520	....	....	18 (34)	28 (53)	53 (100)	90 (170)	5 (9)	12 (23)	19 (36)	28 (53)	53 (100)
High-early-strength	2440	....	....	17 (39)	24 (55)	44 (100)	75 (171)	3 (7)	9 (20)	13 (30)	18 (41)	33 (75)
	2655	....	....	13 (34)	19 (50)	38 (100)	67 (167)	3 (8)	8 (21)	13 (34)	18 (47)	35 (92)

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[a] Bags of filler; 1 bag (80.8 lb.) equals 1 bag cement by absolute volume.

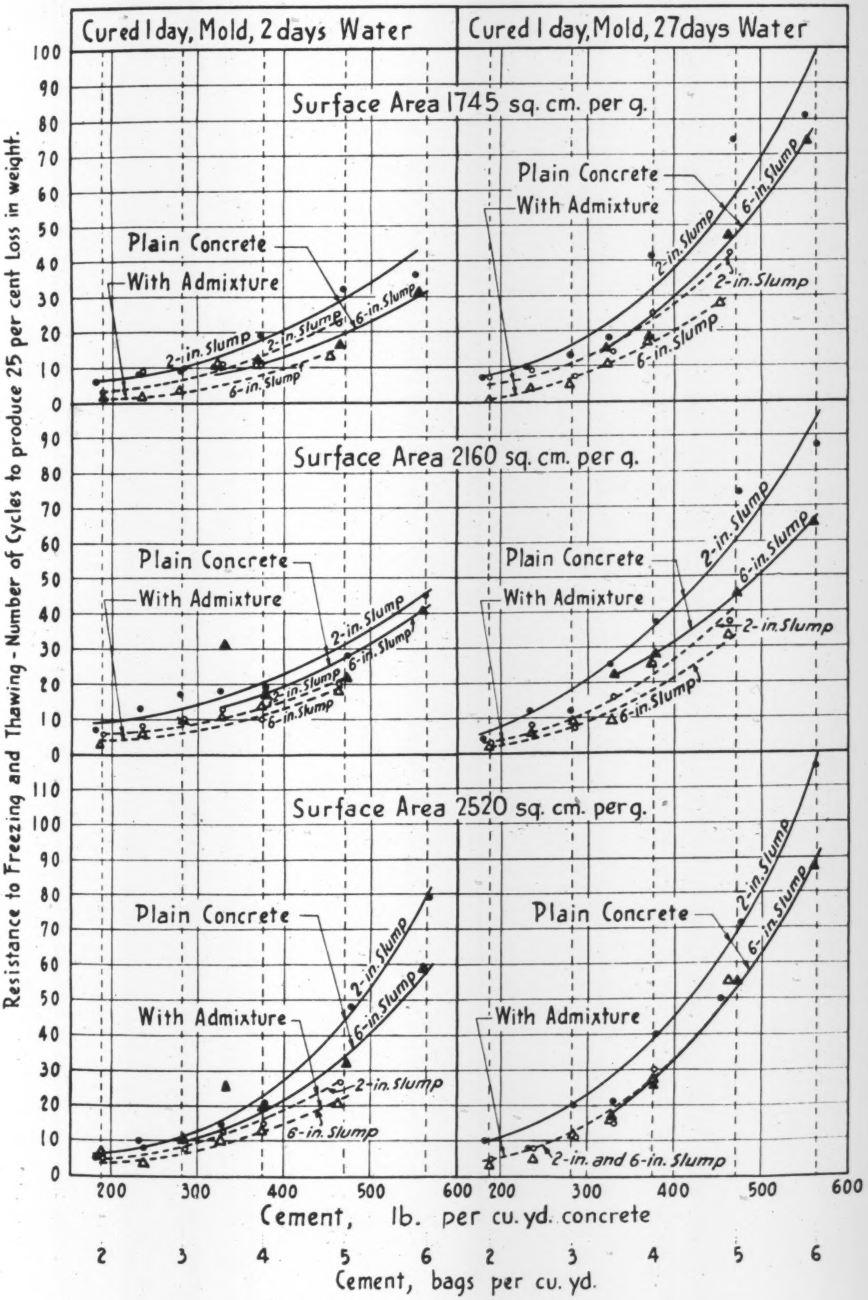

FIG. 8.—Cement Content – Durability Relation for Portland Cement.
Freezing-and-thawing tests of 6 by 6 by 3-in. concrete blocks, frozen at −20 F., thawed at 70 F.; 1 cycle per day.

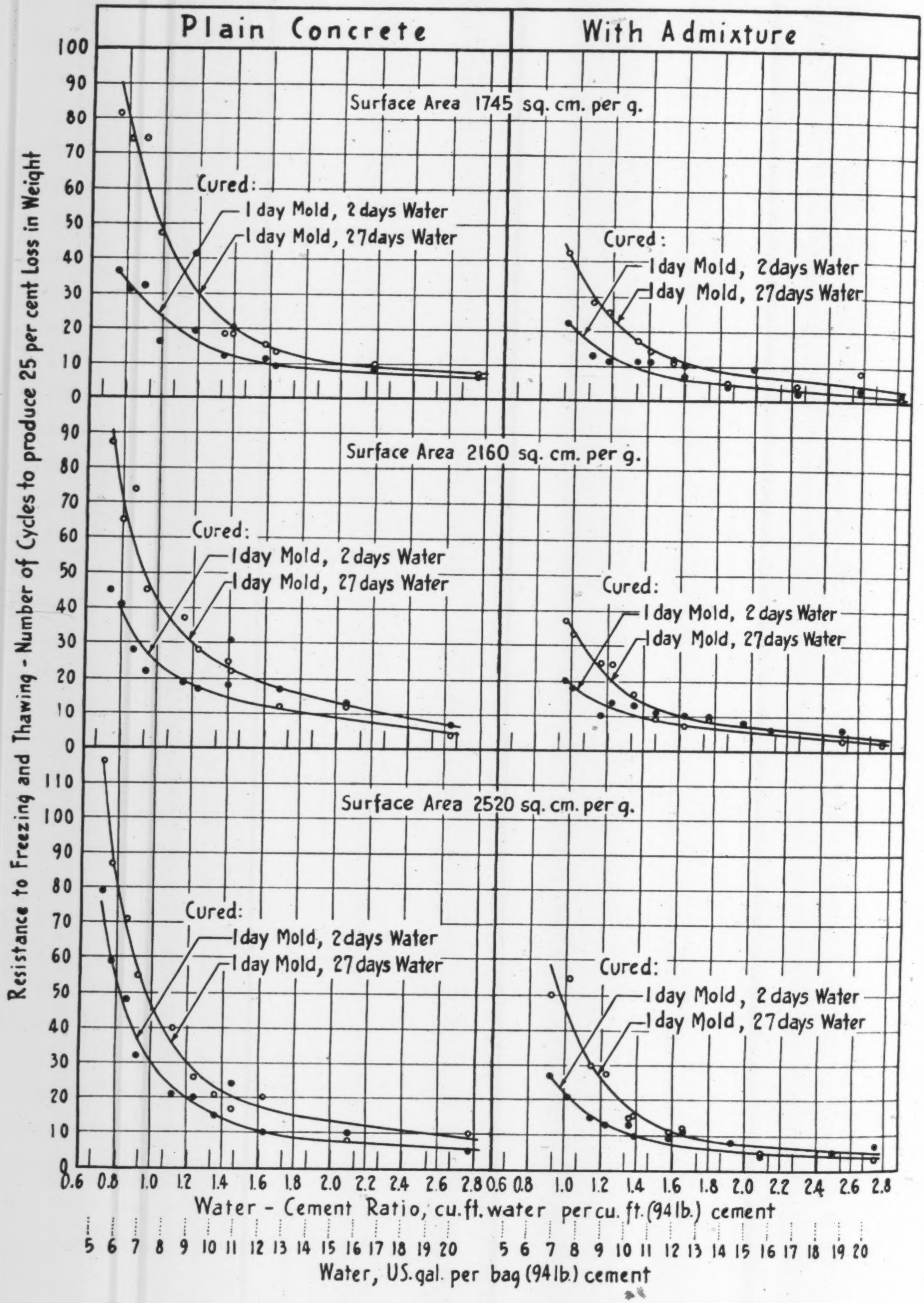

FIG. 9.—Water-Cement Ratio – Durability Relation for Portland Cement.

Freezing-and-thawing tests of 6 by 6 by 3-in. concrete blocks frozen at −20 F., thawed at 70 F., 1 cycle per day. 7 mixes with 2-in. slump; 4 mixes with 6-in. slump.

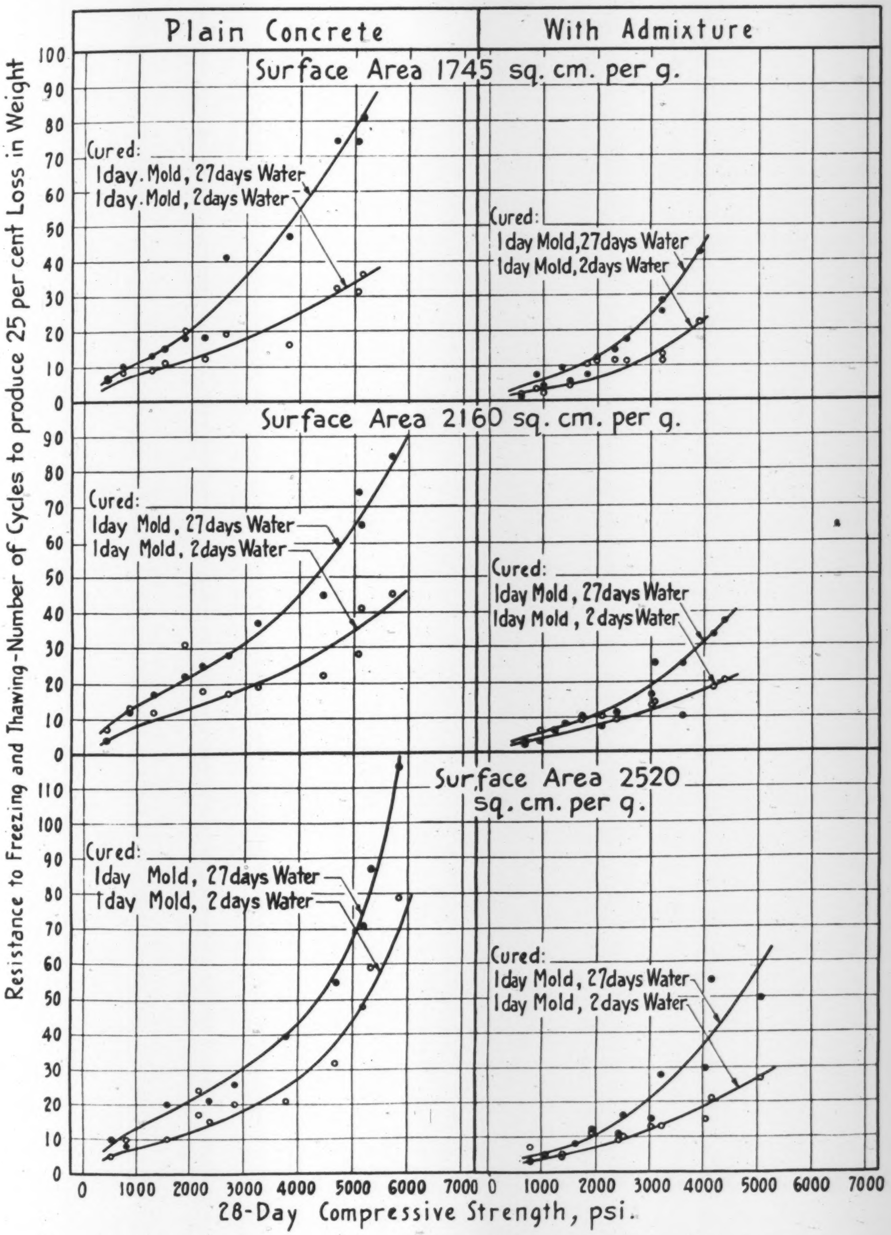

FIG. 10.—28-day Compressive Strength – Durability Relation for Portland Cement. Freezing-and-thawing tests of 6 by 6 by 3-in. concrete blocks, frozen at −20 F., thawed at 70 F., 1 cycle per day. Compression tests of 6 by 12-in. cylinders, cured moist at 70 F. 7 mixes with 2-in. slump, 4 mixes with 6-in. slump.

DURABILITY

In general, freezing and thawing produced only nominal losses in weight of concrete specimens up to a certain point, beyond which however, disintegration progressed very rapidly. The numbers of cycles producing 25 per cent loss in weight were interpolated from curves in which weight losses were plotted against cycles of freezing and thawing.

Effect of Cement Content, Water-Cement Ratio and Strength:

Characteristic relations between durability and cement content are shown in Fig. 8. Table IX gives the durability of the various mixes in freezing-and-thawing cycles and as a percentage of a 5-bag plain mix.

Increase in cement content was accompanied by a relatively higher rate of increase in resistance to freezing and thawing. Addition of one bag of cement to a 2-bag mix increased resistance by 10 cycles; to a 5-bag mix by 40 cycles.

For the same cement content, 6-in. slump concrete had less resistance than 2-in. slump. This decrease was proportional to the increase in water-cement ratio.

Figure 9 shows an intimate relation between durability and water-cement ratio. Resistance increased at a greater rate in the low water-cement ratio range than in the high range. For a given cement there was also a definite relation between durability and strength as shown by Fig. 10.

Effect of Cement Fineness:

For equal cement contents the finer cements gave greater resistance to freezing and thawing. This was most notable for specimens cured only three days before test. For this curing condition the finer portland cements showed better resistances, ranging from 10 per cent in lean mixes to 78 per cent in rich mixes over the corresponding concrete with the coarsest cement. For the same range of mixes, the high-early-strength cement had 20 to 100 per cent greater durability. This is explained by the greater degree of hydration which the finer cements and especially the high-early-strength cements attain at the early ages. For specimens cured 28 days the finer cements and the high-early-strength cements showed increases up to 20 per cent for concretes of the same cement content.

The finer portland cements and the high-early-strength cements produced a given 28-day strength with lower cement contents than the 1745 sq. cm. per g. surface area cement. Where this decrease in cement content was accompanied by an increase in water-cement ratio, resistance to freezing and thawing was reduced. The water-cement ratio for a given durability was about the same for all five cements tested, regardless of what 28-day strength these cements produced. It is therefore apparent that, so far as durability is concerned, the water-cement ratio alone is the governing factor. Hence, if a given durability is desired, a limiting water-cement ratio should be specified, regardless of strength, fineness or cement content. Addition of filler reduced durability of all mixes for both curing conditions. Materials of the type employed in these tests should not be used as admixture or filler where concrete durability is desired.

VOLUME CHANGES

Volume changes at 3 months are given in Table VII and shrinkage results for air curing are plotted in Figs. 11 and 12.

Water Storage:

Only very slight volume changes were noted in any of the specimens stored in water. No appreciable differences were found for varying cement content,

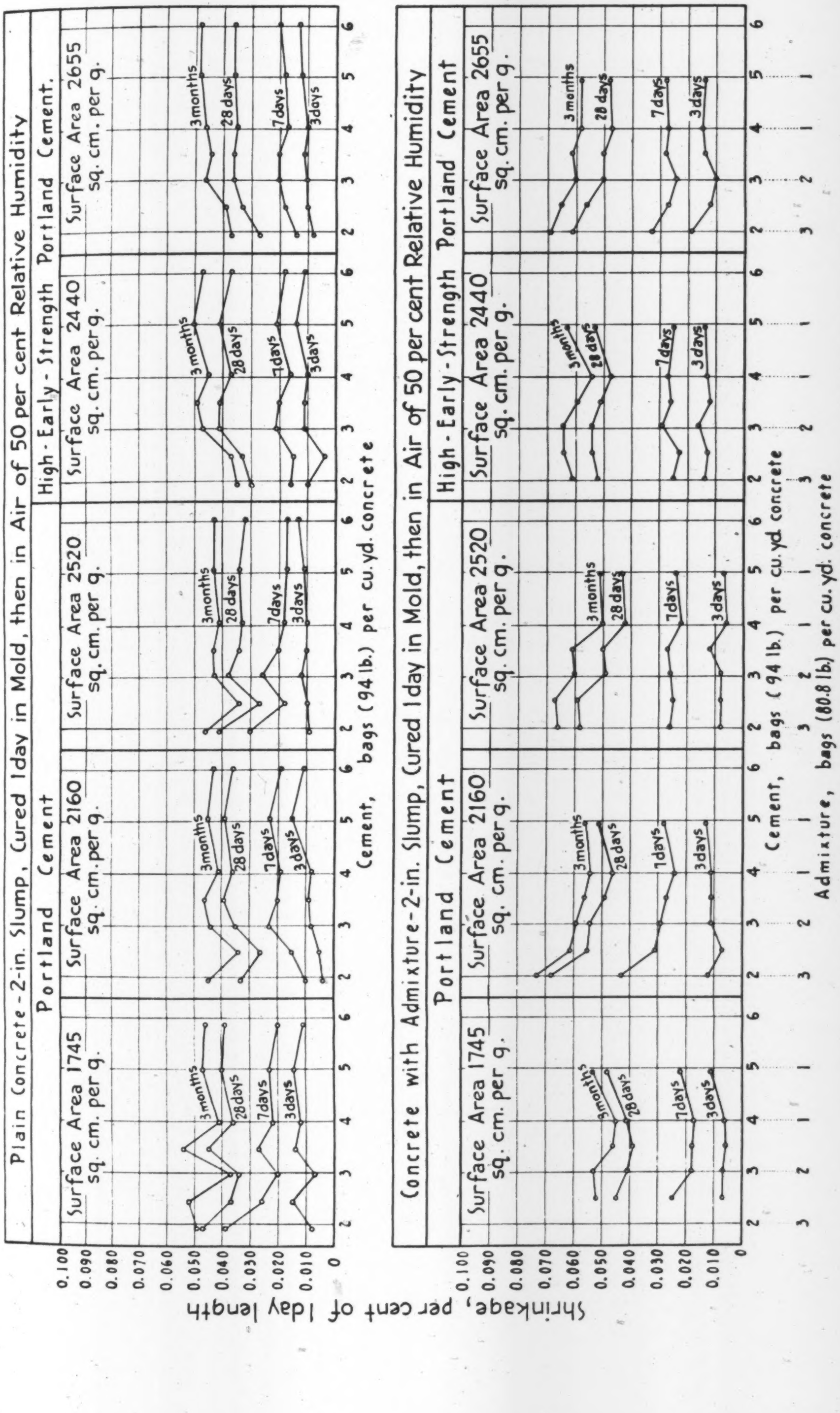

FIG. 11.—Cement Content – Shrinkage Relation for Plain Concrete and Concrete with Admixture, 2-in. Slump

Tests of 3 by 3 by 12-in. concrete beams.

3 portland cements, 2 high-early-strength portland cements.

Admixture (filler)—pulverized limestone, surface area 3450 sq. cm. per g., specific gravity 2.71.

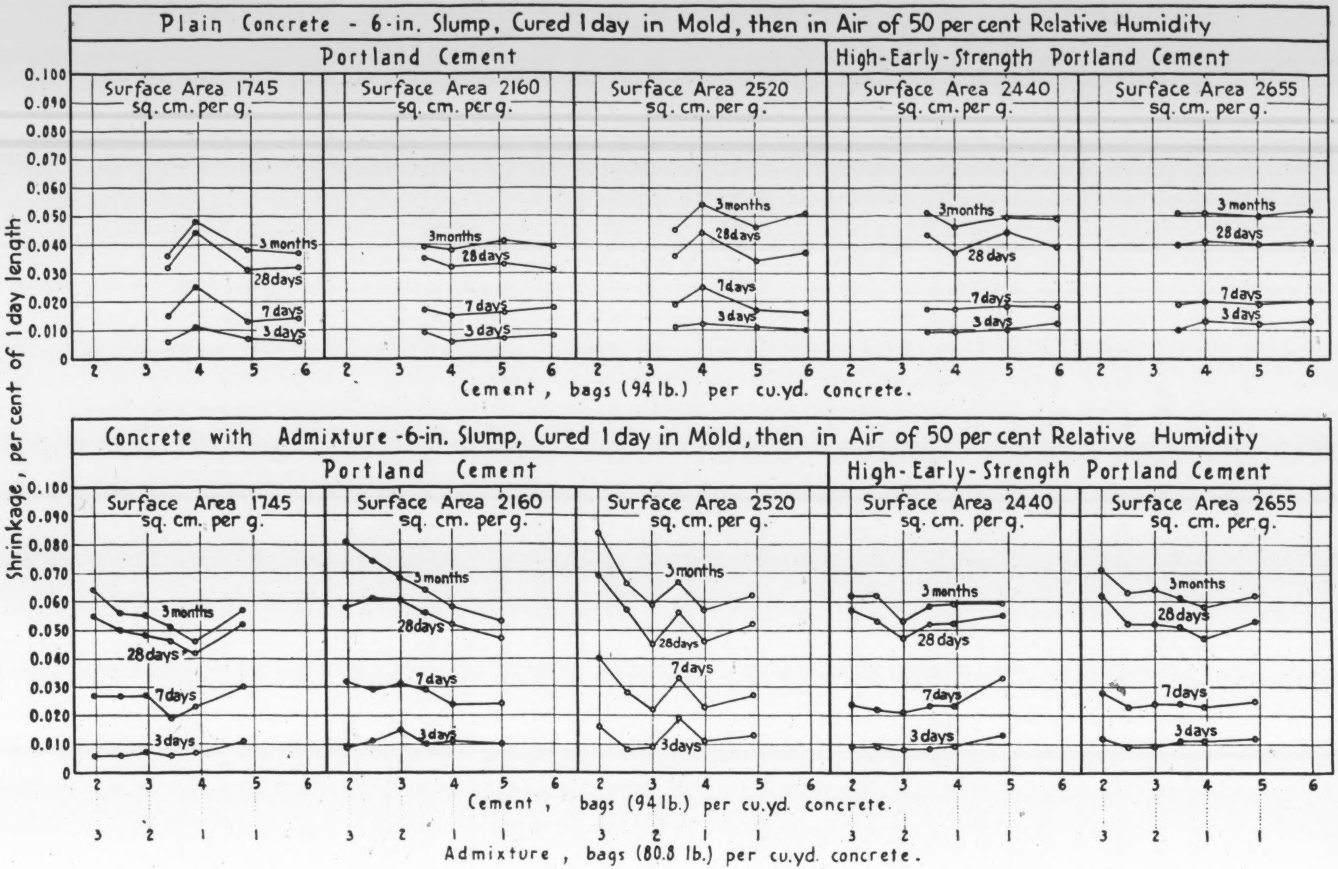

FIG. 12.—Cement Content – Shrinkage Relation for Plain Concrete and Concrete with Admixture, 6-in. Slump.

Tests of 3 by 3 by 12-in. concrete beams.
3 portland cements, 2 high-early-strength portland cements.
Admixture (filler)—pulverized limestone, surface area 3450 sq. cm. per g., specific gravity 2.71.

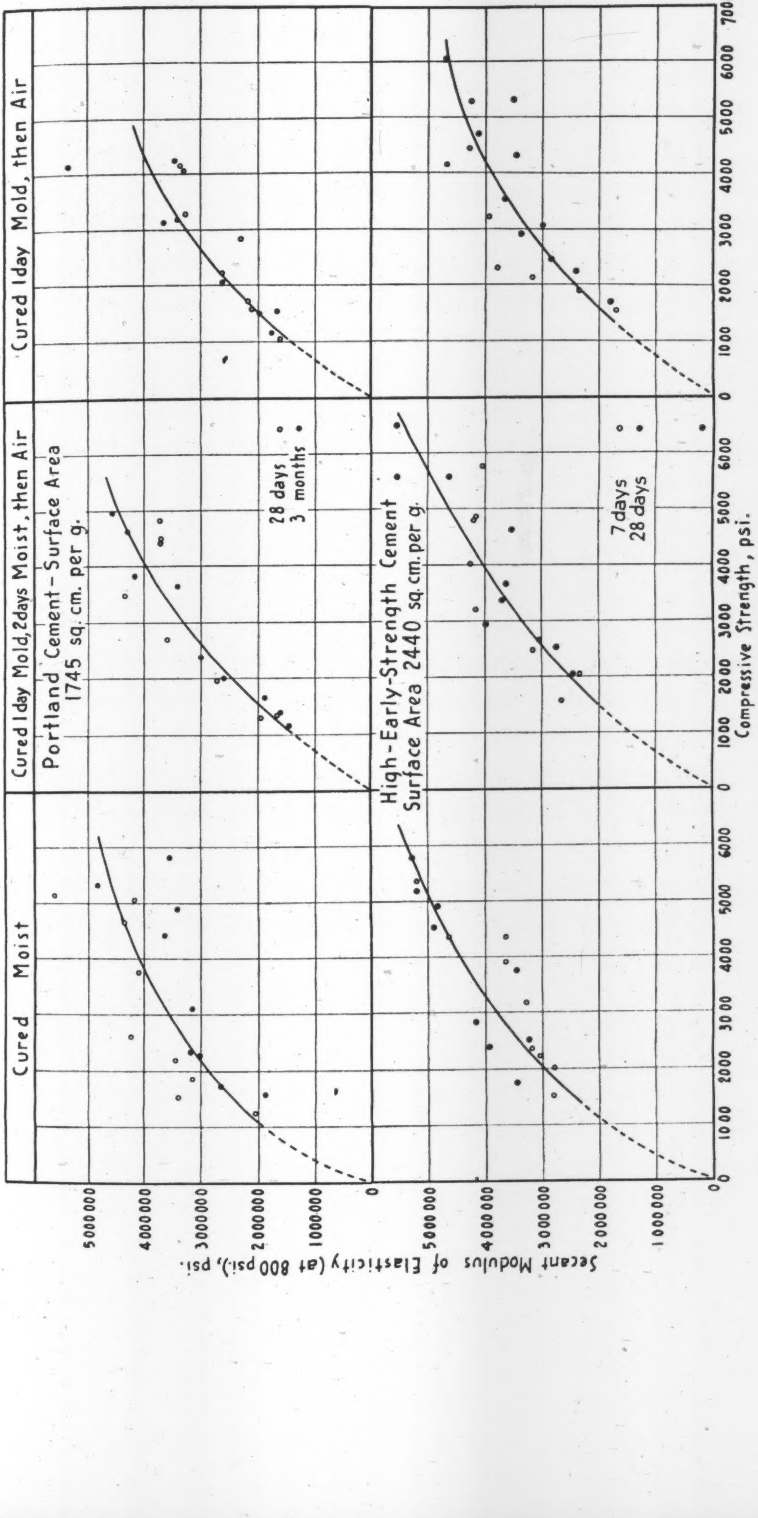

FIG. 13.—Compressive Strength – Modulus of Elasticity Relation—Plain Concrete.
Secant modulus at 800 psi. from stress-strain relation on tests of 6 by 12-in. cylinders.
Compression tests of 6 by 12-in. cylinders, cured as shown.
7 mixes of 2-in. slump, and 4 mixes of 6-in. slump concrete.

fineness, or type. In general, there were small contractions at the age of 3 months. The only exceptions were the 6-in. slump specimens of portland cement with finenesses of 1745 and 2160, which showed slight expansions with increasing cement content.

Volume changes at 3 months ranged from −0.006 per cent to +0.007 per cent for plain concrete, and from −0.011 per cent to +0.007 per cent for mixes with filler.

Air Storage:

No definite relation between cement content and air shrinkage is indicated by the 3-month results. For 2-in. slump concrete shrinkage decreased as cement fineness increased. For 6-in. slump concrete the reverse was found. Water curing for 6 days decreased shrinkage somewhat.

Shrinkage of high-early-strength cement concretes averaged nearly the same as the portland cement results for the 2-in. slump specimens. In 6-in. slump concrete the high-early-strength concrete shrinkage was higher than for the coarser normal portland cements, but was about equal to the one of comparable fineness. Averaging all mixes, we find the 3-month shrinkage ranging from 0.47 in. to 0.61 in. per 100 ft. depending on slump and fineness.

Additions of filler increased the shrinkage of all mixes. Average 3-month shrinkage ranged from 0.55 to 0.73 in. per 100 ft., an increase of 18 to 23 per cent over the plain concrete.

Alternate Storage:

Studies of alternate wet and dry storage specimens are not completed. The 3-month data in Table VII are shrinkages after a 14-day drying cycle.

MODULUS OF ELASTICITY

Stress-strain relationships were determined for all mixes, all cements, and all curing periods. Secant moduli were calculated at 800 psi. The general relation between compressive strength and modulus of elasticity for 2 cements is shown in Fig. 13. The curves are similar to those published by Walker.[8]

TABLE X.—MODULUS OF ELASTICITY OF CONCRETE.

Tests of 6 by 12-in. cylinders.
Values taken from curves as in Fig. 13.

Cement	Surface Area, sq. cm. per g.	Compressive Strength, psi.	Secant Modulus of Elasticity at 800 psi., million psi.[a]					
			Plain Concrete			With Filler		
			Moist	3 days Moist then Air	1 day Moist then Air	Moist	3 days Moist then Air	1 day Moist then Air
Portland	1745	2000	2.86	2.45	2.45	2.85	2.4	2.45
	2160		2.83	2.3	2.35	2.95	2.45	2.5
	2520		2.95	2.2	2.25	3.20	2.2	2.45
High-early-strength	2440		2.95	2.5	2.45	2.75	2.3	2.45
	2655		3.00	2.5	2.45	2.65	2.4	2.45
Portland	1745	3000	3.55	3.3	3.25	3.75	3.3	3.45
	2160		3.60	3.2	3.15	3.80	3.25	3.65
	2520		3.75	3.05	3.10	3.95	3.1	3.20
High-early-strength	2440		3.80	3.35	3.25	3.65	3.1	3.2
	2655		3.90	3.30	3.20	3.55	3.2	3.25
Portland	1745	4000	4.1	3.95	3.85	4.45	4.0	4.2
	2160		4.20	4.0	3.75	4.45	3.85	4.7
	2520		4.30	3.75	3.80	4.45	3.8	3.7
High-early-strength	2440		4.45	4.05	3.90	4.30	3.7	3.8
	2655		4.55	3.85	3.80	4.2	3.85	3.85
Portland	1745	5000	4.48	4.45	..	5.05	4.5	..
	2160		4.70	4.60	4.2	5.00	4.25	..
	2520		4.75	4.30	4.3	4.80	4.4	4.1
High-early-strength	2440		4.95	4.65	4.35	4.8	4.15	4.2
	2655		5.05	4.35	4.25	4.75	4.3	4.3

[a] Calculated from stress-strain relation curves.

Modulus of elasticity appears to be roughly a function of compressive strength regardless of mix or slump and regardless of the age at which a given strength is attained. Cement fineness or type of cement had little effect. It must, however, be noted that the finer cements and high-early-strength cements attain strengths more rapidly and have correspondingly higher moduli at early ages. Addition of filler had little effect on the modulus-strength relation.

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[8] Stanton Walker, "Modulus of Elasticity of Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. XIX, Part II, p. 510 (1919).

Table X gives moduli of elasticity for compressive strengths from 2000 to 5000 psi. for both plain mixes and those with filler for three curing conditions. The data were taken from the strength-modulus curves.

SUMMARY AND CONCLUSIONS

1. Plain concrete mixes containing less than 4 bags of cement were deficient in plastic material and lacked workability. The optimum sand content ranged from 34 per cent for the 6-bag mix to 45 per cent for the 2-bag mix. These lean mixes were improved in workability either by additional cement or an inert filler.

2. Compressive strength decreased with reduction in cement content; the rate of decrease was twice as great in the lean-mix as in the rich-mix range. Close control of quantities, especially of water, is essential for consistent results with low cement factors

3. Addition of inert filler to mixes of 4 bags or less improved strength, but increased drying shrinkage and lowered resistance to frost action. Recourse to filler materials should be avoided where shrinkage and durability are factors.

4. Increased cement fineness improved workability but was ineffective in mixes with $3\frac{1}{2}$ bags or less. Increase in cement fineness was accompanied by an increase in compressive strength at early ages; the effect was less at later ages. High-early-strength portland cements gave substantially greater strengths up to 7 days than portland cement of equal fineness.

5. Water-cured specimens gained steadily in strength up to 3 months, while air-cured specimens showed practically no strength gain after 28 days. Air-cured specimens had lower 3-month strengths than moist-cured specimens; however, this strength decrease was less for the finer cements. The high-early-strength cement showed the least difference between air- and moist-cured strengths, indicating the greater curing efficiency of this type of cement.

6. Shrinkage on drying varied little with cement content, but was affected by the consistency of the mix. Increasing the fineness of portland cement decreased shrinkage of 2-in. slump concrete but increased it in 6-in. slump mixes. Shrinkage of high-early-strength concrete was comparable with that of portland cement concrete for 2-in. slumps, and with high-fineness portland cement for 6-in. slumps.

7. Additions of filler to the mix raised the 3-month average shrinkage from 0.55 in. to 0.73 in. per 100 ft.

8. The secant modulus of elasticity at 800 psi. was roughly dependent on compressive strength, regardless of mix or age. For a given compressive strength, the modulus of elasticity was about the same for all cements. A given modulus of elasticity is attained sooner for the finer cements and the high-early-strength cements. For equal strengths air-cured concrete had a lower modulus of elasticity than moist-cured concrete.

9. Durability as measured by resistance to freezing and thawing decreased as cement content decreased. Reducing cement content from 5 to 4 bags decreased durability by about 43 per cent while an increase from 5 to 6 bags improved durability about 64 per cent. For mixes of the same cement content, the finer cements produced concrete of somewhat greater durability.

10. Concretes without filler of the same water-cement ratio had about the same durability, regardless of cement fineness or 28-day compressive strength.

Water-cement ratio was the governing factor for durability. Shortening the curing period prior to test reduced durability; this reduction was smaller as cement fineness increased and least for high-early-strength cement.

11. Addition of filler reduced durability of concrete in all cases. Plain concrete, even in the lean mixes, showed greater resistance to freezing and thawing than the comparable concrete with filler. In general, for the same water-cement ratios concrete with filler had from 12 to 27 per cent less resistance than plain concrete.

12. The water-cement ratio was shown to govern not only strength but also durability of plain concrete. It also determines amount of cement necessary to produce a given workability.

13. The modern cements produce a 28-day strength of 2000 psi. with a water-cement ratio of 1.34 to 1.46 as compared to 1.0 for cements 20 yr. ago. Thus, if strength alone were considered, the cement content for a 2000-psi. concrete could be reduced to 4 bags or less but the high water-cement ratio of such mixes would result in concrete of low durability.

14. All of the cements followed the water-cement ratio – strength relation established by Abrams, but with the important difference that present 7-day values were all higher than 28-day strengths of 1918 cements.

15. With the greater strength-producing properties of modern portland cements, strength specifications alone no longer assure other necessary qualities in concrete. When durability of concrete for weathering or workability for proper placing is a factor, limitations on water-cement ratio or on a minimum amount of cement should be used in addition to a strength requirement. Even specifying the time-honored 28-day strengths to be attained at 7 days would do much to bring many concrete specifications in line with present-day cements.

DISCUSSION

Mr. W. S. Elliott.[1]—New York City recently adopted a new Building Code. When the Charter Revision Commission studied that code, consultants were brought in in the writing of specifications for concrete. In spite of the data on durability such as those shown by Mr. Gruenwald, they specified plain concrete to develop a strength of 1500 psi. at 28 days, reinforced concrete grade A 1750 psi., and grade B 2200 psi. On anything better than grade B they specified what is known as controlled concrete, in which a laboratory has to predetermine a mix on the basis of the water-cement ratio - strength relationship and for the materials proposed for use.

No one seems to make any attempt to impart sound technical information concerning concrete to the average engineer or architect, except the Portland Cement Assn., and those reports are apt to be considered partisan. We have made good use of their booklet "Design and Control of Concrete Mixtures," by handing it to everyone actively connected with concrete construction. Would it be possible for the A.S.T.M. to devise some way of imparting the data brought out by members, in papers presented, to the rank and file of engineers and architects who are vitally interested in concrete construction? We can never expect all interested parties to become members and to obtain copies of the Book of Standards and the *Proceedings*. However, we could go a long way towards carrying out the chartered purpose of "promotion of knowledge of the materials of engineering and the standardization of specifications and the methods of testing," by distributing free, or at a nominal cost, the pertinent information on any subject such as concrete.

Messrs. H. J. Gilkey[2] **and Glenn Murphy**[2] (*by letter*).—For the most part, the results secured in this extensive and orderly series of tests are confirmatory in that they support conclusions previously drawn from many earlier tests. There are, however, so many interrelated aspects and active fronts to this interesting material, concrete, that laboratory findings do need to be checked and rechecked, for not a few of the earlier conclusions have been found untenable. In addition, only too often do even undisputed laboratory facts require much reiteration before they penetrate to the consciousness of many of those who should be actively applying them. The "lag" is not alone between the laboratory and the field, as may be apparent from parts of this discussion. In the main, however, the writers have commendation only the highest of the excellent investigational job here reported.

Shrinkage:

One of the most interesting indications is the evidence of the upper half of

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[1] Engineer of Tests, Department of Public Works, New York City.

[2] Professor and Head, and Associate Professor, respectively, Department of Theoretical and Applied Mechanics, Iowa State College, Ames, Iowa.

Fig. 11 which shows how nearly negligible both the fineness of the cement and the richness of the mixture appear to be in their effect on the amount of shrinkage from the drying out of the 2-in. slump mixture. The marked shrinkage of neat cement caps, pats, and specimens, and the high volume changes of mortar toppings to sidewalks and floors, from wetting and drying, seem to supply irrefutable evidence that in spite of the reassuring indications of these tests, the cement content of a mixture cannot be disregarded where shrinkage is important.

In considering the general shrinkage or volume-change phenomenon, one should also keep in mind that, while for many concrete structures volume changes from drying and wetting or from temperature changes due to weather changes are the only ones of importance, in a mass-concrete structure the volume change from the heat of hydration is usually of greater importance than that from other causes. There the richness of the mixture is a vital consideration, for the amount of heat generated will be in direct proportion to the amount of a given cement that is present. The fineness of a given cement will, on the other hand, have a much greater influence upon the *rate* of heat generation and volume increase than it will upon the *total amount* of heat generated. Comparisons of the types of problems that differentiate mass concrete from other concrete are discussed at some length in reference (**1**).[3]

That a majority of the specimens should shrink instead of swell under continuous immersion, as appears to be indicated by the top portion of Table VII, does not seem reasonable, and is not in accord with such other tests as the writers have in mind as, for example, references (**2** pp. 334, 349) and (**3**, p. 516, Fig. 164). While the swelling which usually accompanies continuous immersion is only of the order of 0.010 to 0.015 per cent for three months, being apparently somewhat less for the high-early-strength cement, the action does appear to be definitely a swelling, and it seems reasonable that it should be.

The writers commend the author on not asserting that a longer period of moist curing will decrease the amount of ultimate net drying shrinkage, as has sometimes been done in the face of evidence to the contrary and which represents a belief which is rather widely current (**2**, p. 349). Of course, a period of three months is entirely too short a time to secure valid data on that point since normal air drying to constant weight and maximum shrinkage requires a longer period, and these data do not, therefore, supply a basis for a proper commitment on that score.

As the author states some aspects of the effect of the "inert filler" or limestone dust are suggestive of Abrams' tests on admixtures. In Fig. 11 the decrease in the amount of shrinkage as the amount of admixture is decreased is brought out still more strikingly when the shrinkages for the 6-bag mixtures (no filler) from the upper curves are plotted as additional points at the right extremity of each of the corresponding curves of the lower tier.

Strength (Standard Curing):

In his Summary and Conclusions the author states, "Compressive strength decreased with reduction in cement content; the rate of decrease was twice as great in the lean-mix as in the rich-mix range . . . " This is, of course, but another way of saying that a given amount of cement is relatively more effective in a lean mixture than in a rich one, which seems reasonable since a higher proportion of the cement particles will be bonded to particles of aggregate rather than to each other. A recognition of the added relative effectiveness is one of the factors that has come from and with the soil stabilization studies of recent years, and the phenomenon is probably analogous to that of chemical solutions where, in general, the more dilute the solution, the more potent will be a given amount of its active constituent.

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[3] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this discussion, see p. 850.

In considering the effectiveness of cement (or any other factor) on strength, one must discriminate between absolute and relative effects. Refer, for example, to the moist-cured 28-day strengths of Table III (2-in. slump). For a change in cement content from 2 bags up to 3 bags, the strength changes from 435 psi. to 1315 psi., an actual increase of 880 psi. but a relative increase of over 200 per cent. In other words, the 3-bag mixture has three times the strength of the 2-bag mixture. From 4 bags to 5 bags the increase is 1860 psi. (more than twice that above) but the increase is only 57.5 per cent of the 4-bag strength or 31.3 per cent of the 5-bag strength. The increase from 5 to 6 bags is 615 psi. or only a 12 per cent increase. This project supplies the data for some valuable comparisons of the absolute and the relative effects of items for which evidence that is both credible and up-to-date has heretofore been lacking.

The author's results on fineness are quite in agreement with the Boulder Dam studies, which show that increased fineness of grinding is beneficial to strength at all ages and especially in the leaner mixtures, no doubt because of better dispersion and the fact that a higher percentage of the cement is fine enough to function as cement rather than as inert particles of clinker.

The author's Fig. 3, while supplying no new knowledge to anyone who has followed the evolution of cement over the past 20 yr., does set forth neatly and lucidly the essence of that progress as regards strength. Not only have there been great changes in the quality of portland cement itself, but concepts have also changed. Not a few of the recognized authorities in the field will now admit that the grading of the aggregate and a great many other factors exert a significant influence upon the strength of concrete. Yet these changed concepts do not necessarily decrease the usefulness of the well-established water-cement ratio - strength relationship, as can be so readily seen by noting the essential parallelism of the curves of the author's Fig. 3. The old Abrams relationship expressed on the basis of relative or percentage strength is still a most useful device for estimating or evaluating the extent of strength change corresponding to a given change in water-cement ratio. This use of the relationship was pointed out in reference (4) and tables of useful ratios are supplied in reference (5). The three curves of Fig. 3 reduced to a percentage basis can be almost exactly superimposed. About equally close agreement is found for the curves of the author's Fig. 4.

Strengths (Water Curing Preceding Exposure to Air):

All specimens exposed to the air after a period of moist curing were tested dry. In this connection the writers believe that attention should have been directed to the 15 to 30 per cent greater strengths secured from specimens which are dry at test as compared with the strengths which the same specimens would have developed had they been saturated by immersion for one or two days just prior to testing. Increasing recognition is being accorded to the fact that, for most purposes, comparisons of strength are only valid for specimens which are in like condition as tested. Because the saturated condition is much the simpler to attain, and because standard-cured specimens are always saturated, the saturated or re-soaked condition has been generally adopted as standard. There are many degrees of dryness, and a considerable period of air exposure is necessary to attain a more or less constant moisture state in a given environment. On the other hand, water is about equally wet the world over and resumed curing progresses slowly, so that a day or two of immersion, more or less, has no significant influence upon the wet-tested strength secured.

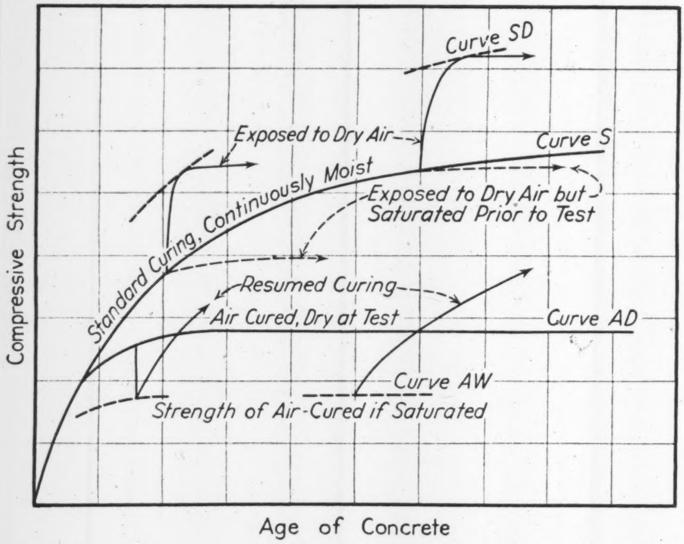
Curve SD
Exposed to Dry Air
Curve S
Standard Curing, Continuously Moist
Exposed to Dry Air but Saturated Prior to Test
Resumed Curing
Air Cured, Dry at Test
Curve AD
Curve AW
Strength of Air-Cured if Saturated
Compressive Strength
Age of Concrete

FIG. 1.—A Typical Diagram Showing the Nature of the Curing, Air Drying, Resoaking, and Resumed Curing Effects on the Compressive Strength of Concrete.

The accompanying Fig. 1 illustrates the nature of the strength variation for different combinations of air and water curing. The air-cured strengths of the author's "cured one-day, moist, then air" were either placed in air at the age of one day upon removal from the mold, or else at the age of three days after two days in the fog room following removal from the mold. In the first case, the strengths at different ages should follow along the *AD* (air-dry) line and if air storage began at an age of three days, the strength curve would be similar to *AD* but would lie somewhat above it. More detailed consideration of the general curing phenomena can be found under reference (6).

The essential correctness of the qualitative action of Fig. 1 has been demonstrated by many test series in the writers' laboratories and is amply supported by the results of tests by other investigators. Since the maximum age reported in the author's tests is three months, the writers have plotted on the accompanying Fig. 2 the heavy lines representing mean results from an extensive series on small 2 by 4-in. specimens, the strength of the standard-cured specimens at three months being taken at unity (or 100 per cent). On this diagram have been plotted corresponding points from data reported by Gonnerman and Shuman of the Portland Cement Assn. laboratory (8, p. 545). The Gonnerman-Shuman percentages superimpose exactly upon the standard-cured (*S*) curve, and the curves for the two concretes exposed to the air after one day moist lie somewhat above the corresponding *AD* curve, as would be expected from the slower drying out of the larger 6 by 12-in. cylinders. The *AD* curves flatten out only as drying progresses far enough to produce a moisture shortage sufficient to halt curing action (hydration).

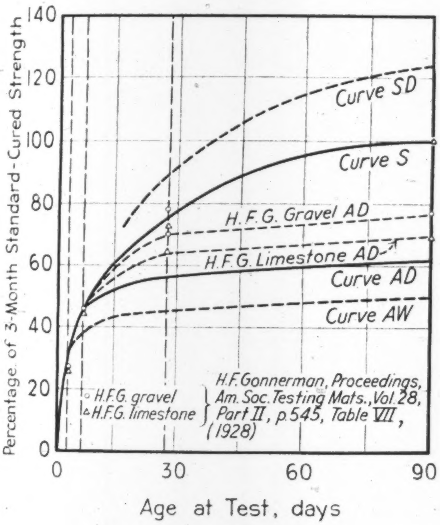

FIG. 2.—Typical Curing Diagrams with Strengths Expressed as Percentages of 3-month Standard-Cured Strength. Portland Cement Assn. tests plotted on for comparison.

Heavy lines represent data from Iowa State College. Plotted points and light lines are from P.C.A. tests.

While Gonnerman and Shuman did not immerse their air-cured specimens prior to test, as would have been desirable, they did frankly recognize that their dry-tested strengths were not properly comparable with their standard-cured strengths for they state: "The data for the different curing conditions are not directly comparable since the moist-cured specimens were tested damp while the specimens cured for a time in the moist room and then in air in the laboratory were either partially or well-dried when tested. The extent of the drying depended on the duration of air storage" (8, p. 547).

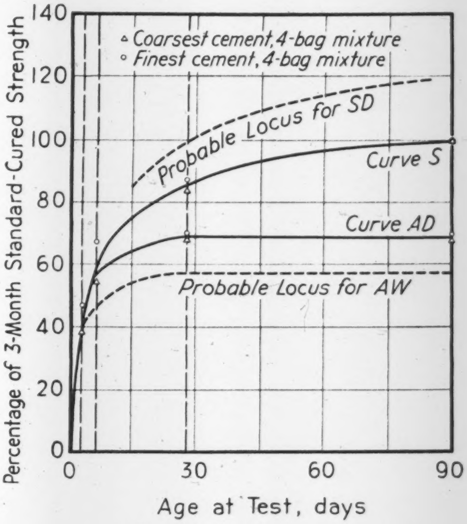

FIG. 3.—Plotted Data for Some of the Normal Portland Cement Concretes Reported in the Paper with Probable *SD* and *AW* Curves Added.

After about 15 yr. of repeatedly pointing out the really significant differences between wet-tested and dry-tested strengths, it is discouraging to find these differences being so generally disregarded and unrecognized by those actively engaged in concrete testing and research. Only a few weeks ago it was reported to the writers, presumably on the best of authority, that a leading commercial laboratory still "stores" many of its control samples in the air of the laboratory and claims that the difference between the strength secured that way and by moist curing is negligible.

In the accompanying Fig. 3 are shown the plotted data for the coarsest and the finest cements of the author's 4-bag mixture, the two intermediate curves being from the author's data and the top and bottom curves representing reasonable *loci* for the conditions that were not investigated. Thus, the standard portland cement which was in air after one day moist actually developed at 3 months something less than 60 per cent of the standard-cured 3-months strength. While, therefore, the beneficial effect of moist curing is qualitatively what the findings indicate, its quantitative value is appreciably understated for anyone not realizing that dry-tested concrete is from 15 to 30 per cent stronger than the same concrete would be if saturated just prior to test.

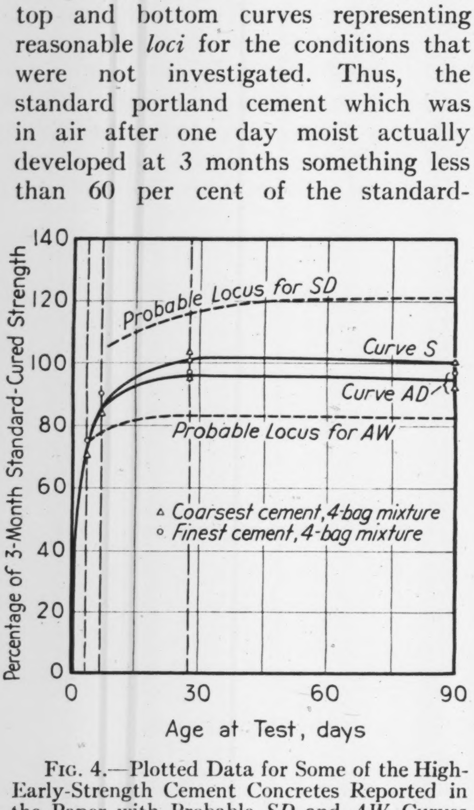

FIG. 4.—Plotted Data for Some of the High-Early-Strength Cement Concretes Reported in the Paper with Probable *SD* and *AW* Curves Added.

The accompanying Fig. 4 shows the corresponding data for some of the high-early-strength concretes of these tests. While for high-early-strength cement the beneficial effect from prolonged curing is much less than for ordinary portland cement, there is still present in the data of the paper a misleading inference, the actual difference being considerably greater than the apparent 5 or 10 per cent differential between the dry-tested air-exposed concrete and the moist-tested standard-cured concrete.

Comparison of Cements on Basis of Curing Needs:

One of the most interesting features of this paper, which is illustrated and emphasized by comparing the relative positions of the *AD* curves in the accompanying Figs. 3 and 4 is the essential difference between a high-early-strength and an ordinary portland cement with respect to continued curing. Obviously, a relatively short period of moist curing for high-early-strength concrete will net a high percentage of the ultimate possible gain.

As has been generally recognized for some time, the finer a cement is ground, the more of the characteristics of a high-early-strength cement does it acquire, due presumably to the greater percentage of fine particles which are highly active. The plotted data of Fig. 3 and Fig. 4 do not indicate a great difference due to fineness of grinding, but the difference is a quite consistent one in favor of the finer-ground cement of both the regular portland and the high-early-strength varieties.

Modulus of Elasticity:

The modulus of elasticity is discussed briefly in the last section prior to the conclusions. The first two sentences convey a misleading and what must be an impossible implication that "secant moduli were calculated at 800 psi." for "all mixes, all cements and all curing periods." Not a few of the mixtures had ultimate strengths well under 800 psi. at all ages, as can be noted by reference to Tables II to VI inclusive.

While the technique described could obviously have been applied only to the stronger concretes, the writers still feel that the choice was not a happy one for two reasons: (1) For a wide range of strengths, such as these tests included, 800 psi. falls high on the stress-strain diagram, well into the curved portion, for some concretes and relatively near the origin for others. (2) The true origin for a stress-strain diagram is a highly uncertain point. Because of instrumental lag, and lag within the specimen as well, no doubt, the first few observations of strain are likely to be the least dependable of those on the entire stress-strain diagram.

To have drawn in a mean straight line through the plotted points up to 25 or 30 per cent of the ultimate strength of each concrete (without attempting to pass it through the zero point) would have given more dependable and comparable values for the slope that defines the modulus. After studies of stress-strain data for concrete extending over from ten to eighteen years, the writers have not yet evolved what they consider to be a fully satisfactory technique for the determination of the slope of the line that evaluates Young's modulus. Some of these investigations constituted the basis for a recent publication (8), in which attention is focused upon some of the other problems involved in comparing varied stress-strain data.

Referring now to the plotted data of Fig. 13, the writers contend that the dotted extensions of such curves are not justified and tend to make the relationship appear to be more precise than is really the case. Actually, most of the constellations shown in Fig. 13 are rather short, wide bands that do not define relationships which are nearly so definite as one is apt to infer from glancing at the figure or at Table X. This criticism, if it be considered as such, does not apply to these tests only, for the author's data show a better relationship between the ultimate strength and Young's modulus of elasticity than do most of the many other tests which the writers have seen, including their own.

The writers feel that, for the present, the following and little more can safely be said relative to the relationship of these two important properties: "As many other investigations have also indicated, the compressive modulus of elasticity of a concrete is roughly proportional to its ultimate compressive strength, but the trend is rather general and not narrowly defined. As strengths rise above about 4000 psi., the value of the modulus increases but little."

Many tests, not only by the writers but by others such as those of Thoman and Raeder (9, p. 236), confirm the indications of the tests reported in this paper that the convenient and widely used assumption that Young's modulus of elasticity is approximately equal to 1000 times the compressive strength of the concrete, is approximately true only for the low-strength concretes and not at all applicable to the usual current mixtures. This relationship will generally give too high a value for the modulus.

The writers, in closing, congratulate the author upon the excellent job which he has done, and express the hope that their comments and references may so supplement the author's work as to enhance, rather than to detract from, the value and interest of the data presented.

MR. DUFF A. ABRAMS[4] (*by letter*).—This investigation covers a range of lean concrete mixes, concerning which little was known. I wish to compliment

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[4] Consultant on Concrete, New York City.

Mr. Gruenwald on the comprehensive program of tests on which his conclusions are based. One finds it difficult to disagree with conclusions which are based on approximately 10,000 skillfully made tests. Attention is called also to the fact that a preliminary exploratory series of 166 hand-mixed batches was studied before beginning the main series of machine-mixed batches. The practice of basing conclusions on a number of parallel tests made on different days is recommended for the consideration of all experimenters on the properties of concrete and cement.

It is gratifying to see that the water-ratio-strength relation has been verified for the wide range of mixes, types of cement and ages covered by these tests. The curves in Fig. 4 give added confidence in the validity of this relationship, which is still being disputed in certain quarters. Out of some 300 tests in Fig. 4, only a few points depart appreciably from the smooth curves. Within the usual range of water-cement ratios, large quantities of inert filler cause only minor departures from the parallel curves for cement only.

The writer was particularly interested in Mr. Gruenwald's conclusion that the water-cement ratio is a satisfactory criterion of concrete durability as measured by repeated freezing and thawing.

Mr. Gruenwald has properly called attention to the changes in concrete strength since the writer announced the water-cement-ratio law in 1918. The 28-day strengths which were considered satisfactory 21 yr. ago are not now a safe guide to concrete durability when they are obtained with a too low cement factor. This is no criticism of the validity of the water-cement-ratio law, but comes about from two causes:

1. The 28-day strength is a purely arbitrary basis for design purposes and does not reflect the ultimate quality of the concrete.

2. The vastly improved 28-day concrete strength resulting from properly manufactured modern cements is due largely to a change in cement composition which naturally could not have been foreseen 22 yr. ago when the water-cement-ratio law was being formulated. Some improvement has resulted from finer grinding.

The 28-day concrete strength of properly manufactured cements of the present day is about twice that of the average cement of 1916–1918. If a comparison had been made on the basis of strengths after moist curing for 1 yr., the difference between the 1918 and 1938 cements would not have been so great.

A few months ago, the writer had occasion to make some searches in the literature with reference to the changing compound composition of American portland cements, and found that the principal change was in the amount of tricalcium silicate; average values were found to be about as follows:

Year	Tricalcium Silicate, per cent
1880	17
1890	22
1900	28
1910	35
1920	42
1930	47
1937	52

The advancing percentage of tricalcium silicate was, of course, accompanied by a corresponding reduction in dicalcium silicate. The researches of Bogue and others have shown that the tricalcium silicate is the principal strength-giving compound up to 28 days.

During the period 1895 to 1910 certain well-known brands of cement, which were imported from Germany and England, showed tricalcium silicate content 10 to 15 per cent higher than the average American cements; this difference in compound composition was, no doubt, largely the cause of the deservedly high reputation of these European cements among American users.

MR. ERNST GRUENWALD[5] (*author's closure by letter*).—While Mr. Elliott's comments are concerned more with sources of information on concrete than with the paper under discussion, it should be noted that the *Proceedings* of the Society, as well as those of the American Concrete Institute, provide a wide range of readily available material. In addition, technical data published by the Portland Cement Association and by individual cement manufacturers, while *ex parte* in origin, must stand the test of use; it follows, therefore that information from these sources must be reliable or else fail in its primary purpose of building good will for the product concerned.

With reference to the discussion of H. J. Gilkey and Glenn Murphy: The results of the shrinkage tests were somewhat surprising. It is generally assumed that a reduction in cement content is accompanied by a decrease in shrinkage. This is true when comparing extremely rich mixes containing from 6 to 10 bags of cement with 5- or 6-bag mixes. The lean mixes of this investigation show no benefit, as far as shrinkage is concerned, from the reduction in cement, because of the increased water requirements. On the other hand, the richest mix contained only 6 bags of cement which were not sufficient definitely to bring into play the effect of greater quantities of cement on shrinkage.

The slight shrinkage shown by water-cured specimens is not in accordance with other published tests but the results seem not unreasonable. All the principal cement compounds in hydrating display a tendency toward shrinkage. The volume of the hydrated compounds is less than that of the dry compounds plus mixing water. Recent studies in our laboratory by M. A. Swayze and L. S. Brown disclosed the facts that the principal compounds also adapt themselves to their surroundings by formation of the hydrate on surfaces in open areas rather than by direct reaction of water in place. With richer mixes than those employed in these tests, the tendency for expansion in water will, of course, be greater due both to the greater number of expanding grains per unit volume and to the greater particle interference in the denser paste. However, we have just completed 3-month tests on one of our high-early-strength cements which still shows 0.001 per cent shrinkage with a $7\frac{1}{2}$-bag mix. The shrinkage with a $3\frac{1}{2}$-bag mix amounted to 0.004 per cent.

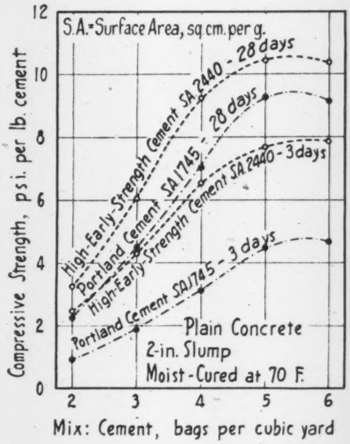

FIG. 5.—Strength per Unit Cement Content.

With reference to the statement of H. J. Gilkey and Glenn Murphy that the given amount of cement is relatively more effective in a lean mixture than in a rich one, I have plotted the accompanying Fig. 5 which shows compressive strength in pounds per square inch obtained per pound of cement in mixes containing from 2 to 6 bags of cement. It is seen that the strength return per pound cement is at a maximum for cement contents between 5 and 6 bags and decreases rapidly for mixes leaner than 5 bags, indicating a very low efficiency of cement in the leaner mixes. The leaner mixes require a large amount of water, producing a paste of low cementing value. In the extremely rich mixes the advantage of a low water-cement ratio paste is partially offset by the thickness of the cementing medium, so that after an optimum is reached the efficiency in the rich mixes decreases slightly.

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[5] Engineer, "Incor" Division, Lone Star Cement Corp. New York City.

In laying out our program, we were well aware of the effect that wetting air-cured specimens has on compressive strength, but we decided to test the specimens as cured. This was prompted by the thought that concrete beams, columns, etc., in reinforced concrete structures, for example, may never come in contact with water after the curing period is completed. To test specimens supposed to represent the strength of these dry structural members in a wet condition seemed to us to be wrong. The test specimens when wetted are under strain due to differences in water absorption from the surface to the center, while the concrete member is free from such strains once it comes to a uniform condition.

The amount of strain developed in air-dry cylinders by 24-hr. water soaking must be variable, since permeability must vary with cement content, cement fineness, and perhaps even with cement composition.

We have cylinders for test at 1, 5 and 10 yr. and the study of the effect of curing will be continued.

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A STATISTICAL ANALYSIS OF COMPRESSION TESTS ON MORTAR CYLINDERS, CUBES AND PRISMS[*]

By H. W. Leavitt[1] and H. A. Pratt[1]

A study has been made in recent years to determine the best standard form of test specimens for measuring the compressive strength of mortars. Among the forms, or types, of test specimens under consideration, and which are herein discussed, are the 2-in. cube, the 2 by 2 by 4-in. prism, and the 2 by 4-in. cylinder. The performance records of these three types of mortar specimens vary so little that only through the use of statistical methods can the data be properly evaluated. This study of specimen forms has been linked with the testing of portland cement,[2] and also with the testing of commercial sands for use in portland cement concrete.[3]

In order to evaluate properly the different types of test specimens, reasonably large numbers of specimens are required. As in previous cases,[3] this fact brought the problem to the attention of Subcommittee XI on Evaluation of Data, of the Society's Committee C-9 on Concrete and Concrete Aggregates.

In addition to the interest shown by members of the Society's Committees C-1 on Cement and C-9, in general, Subcommittee IX on Specifications and Methods of Tests of Aggregates of Committee C-9 has for the past few years been attempting to standardize certain details in connection with the testing of sands in compression.[4] This fact led to the inclusion in this report of a series of tests relating to commercial sands.

In brief, this report covers a statistical study of three series of data. The first two series relate to compression tests on portland cements, and the third series relates to compression tests on commercial sands. Each series involved 60 repeat tests on 60 different days, on which extreme care was taken to make each day's work identical.

Description of Tests

The specimens used in the three series of tests were 2-in. cubes, 2 by 2 by 4-in. prisms,[5] and 2 by 4-in. cylinders. Three hundred and sixty specimens (six each day) of each type were fabricated in the laboratories of the Maine Technology Experiment Station by Horace A. Pratt, Assistant Engineer of the Station. One-half of the specimens were tested at the age of 7 days, and the remaining specimens at the age of 28 days.

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[*] This paper was prepared from a report of compression mortar tests made for Subcommittee XI on Evaluation of Data of the Society's Committee C-9 on Concrete and Concrete Aggregates by the Maine Technology Experiment Station. Its presentation at the annual meeting was sponsored by Committee C-9.

[1] Secretary, and Assistant Engineeer, respectively, Maine Technology Experiment Station, University of Maine, Orono, Me.

[2] Report of Investigation of Pebble Mortars by Fourteen Laboratories, *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 267 (1938).

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Standard Specifications for Fine Aggregate for Portland Cement Concrete Pavement or Base Course, Highway Bridges and Incidental Structures (Specification M - 6), *Ibid.*, p. 18.

[5] For description of prism molds see paper by H. J. Gilkey and H. W. Leavitt, *loc. cit.*, pp. 284, 285.

The *first* series of tests were made on 360 specimens fabricated according to the methods outlined in A.S.T.M. Tentative Method of Test for Compressive Strength of Portland-Cement mortar (C 109 - 37 T),[6] the aggregate consisting of graded Ottawa sand.

The *second* series consisted of the same number of specimens. These were made of coarser aggregate as outlined in the report of the investigation on pebble mortar.[2] The method which was used in this series was known as the "Pearson mix" and included non-absorptive aggregate ranging from 0 to $\frac{3}{8}$ in.

TABLE I.—BASIC MIXES FOR THE THREE SERIES.

	Series I— C 109 Mix	Series II— Pearson Mix	Series III— C 87 Mix
Low absorption gravel (3/8 in. to No. 4), g	0	1250	0
Standard Ottawa sand (Nos. 20 to 30), g	0	520	0
C 109 sand (graded Ottawa), g	1300	0	0
Ottawa banding sand, g	0	315	0
Cement, g	470	375	600
c/w (cement-water ratio) by weight	1.88	1.88	1.67
w/c (water-cement ratio) by volume	0.8	0.8	0.9
Water, ml	250	200	360
Maine commercial sand, g.	0	0	Enough to produce flow of 100 ± 5[a]

[a] Limits for these 60 Maine sands were found to be 1293 to 1986 g.

The *third* series of tests involved 60 different commercial State of Maine sands tested at the same ages and in the same types of specimens as the two previous series.

The exact proportions of materials or basic mixes used in each of the three series of tests are given in Table I.

Series I:

All the tests in series I were made in accordance with A.S.T.M. method C 109 - 37 T. Test specimens consisted of 2-in. cubes, 2 by 2 by 4-in. prisms, and 2 by 4-in. cylinders. Separate batches were hand-mixed for each type of test specimen, and six specimens of each type were made from each batch, three for testing at the age of 7 days and three for testing at the age of 28 days. The entire program was repeated 60 different times on as many days. All specimens in series I were made between November 5, 1937, and January 24, 1938. Batches were made on successive days as far as possible, when Sundays and holidays would not interfere with the mixing, cleaning, or testing. The data are presented for analysis in their entirety, as no attempt was made to disregard extraneous results. Temperature and humidity conditions were kept within the A.S.T.M. requirements. A slump test was made each day upon one of the batches.

Although no statistical use is reported herewith, additional information was obtained in the form of consistency measurements. The first of these, a slump test, was made in accordance with A.S.T.M. Tentative Method of Test for Consistency of Portland-Cement concrete (D 138 - 32 T), except that the cone was half size (2 by 4 by 6 in.) and was filled in two layers and tamped with a bullet-pointed rod $\frac{3}{8}$ in. in diameter. In addition to the slump test, each day a second batch was tested for workability by means of the Burmister flow trough[7] as modified by Lewis H. Tuthill.[8] The modification of the Burmister trough was as follows: The dimensions of the trough were one-half those of the larger Burmister trough. It was mounted on a block of wood 4 by 4 by 15 in. by means of trunnions on the back of the trough.

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[6] *Proceedings,* Am. Soc. Testing Mats., Vol. 37, Part I, p. 726 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 476.

[7] Donald M. Burmister, "The Concrete Flow Trough," *Proceedings,* Am. Soc. Testing Mats., Vol. 31, Part II, p. 554 (1931).

[8] Testing Engineer, The Metropolitan Water District of Southern California, Banning, Calif.

and supports attached to the block. The open end of the trough was lifted 1 in. and dropped by means of a cam and crank attached to the block. Additional workability tests were made on one of the batches from each day's work, using the 10-in. flow table (A.S.T.M. Method C 87 – 36).[9]

The cement used was from the standard stock supply of the Maine Technology Experiment Station laboratory. The portland cement met all of the requirements of A.S.T.M. Standard Specifications for Portland Cement (C 9 – 38).[10] The method of molding the cube was as follows: A layer of mortar about 1 in. in depth was placed in each of the six cube molds. The mortar was then tamped 32 times in each mold in about ten seconds and in four rounds of eight tamps. The pressure applied to each stroke was about 150 g. The tamper had a cross-section of $\frac{1}{2}$ by 1 in. and was approximately 6 in. in length and made of medium hard rubber. Each round was made at right angles to the previous round and consisted of eight adjoining tamps over the surface of the specimen. Four rounds of tamping (32 tamps) were made upon each cube before going to the next cube. When the tamping of the first layer of the six cubes was completed, the forms were filled with the remaining mortar and again tamped as specified for the first layer. The mortar was then leveled off, great care being taken to leave the mortar slightly above the tops of the molds. The tops were then finished flush with the top of the molds, using a trowel (in order to facilitate the troweling, it was found convenient to use the rubber tamper as a squeegee to clean the mortar from the tops of the molds and to remove some of the excess mortar).

The prisms were filled and tamped with the same tamper by exactly the same method as for the cubes, with the exception that twice as many tamps were used per layer on each prism specimen, due to the area of the tamping surface being twice that of the 2-in. cubes.

The cylinder molds (2 by 4 in.) were filled in three successive layers and tamped with 25 tamps per layer. For filling these molds, a metal tamper was used. This tamper had a total length of about $6\frac{1}{2}$ in. and was 1 in. in diameter for $1\frac{1}{4}$ in. of the tamping end, the remaining $5\frac{1}{4}$ in., which served as a handle, being $\frac{5}{8}$ in. in diameter. The tamper weighed approximately three-fourths of a pound.[11]

The molds used for the cubes and the cylinders were of brass, whereas the molds used for casting the prisms were of polished steel. In connection with the steel prism molds, it was found desirable to coat the steel base plate with paraffin wax to prevent adhesion of the specimen. A mineral oil was found adequate to prevent adhesion of the specimen to the other parts of the steel mold, and sufficient for all the parts of the brass molds. The molds were not sealed to the base plates.[12]

Details of curing and testing were in accordance with A.S.T.M. requirements. None of the specimens was capped, with the exception of one or two of the cylinders which were found to have very poor upper bearing surfaces. The cubes and prisms were all tested in a direction at right angles to the direction in which they were molded. The cylinders were tested in the same direction in which they were molded. All specimens

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[9] *Loc. cit.*, see footnote 4.

[10] 1938 Supplement to Book of A.S.T.M. Standards, p. 95.

[11] Standard Method of Making Compression and Tension Tests of Fine Aggregate for Concrete (Method T – 35), Standard Specifications for Highway Materials and Methods of Sampling and Testing, Am. Assn. State Highway Officials, p. 107 (1935).

[12] H. W. Leavitt, "A Study of Plastic Mortar Cubes," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 321 (1937). In this report the sealing of the molds to the base plates was found to have no appreciable effect on test results.

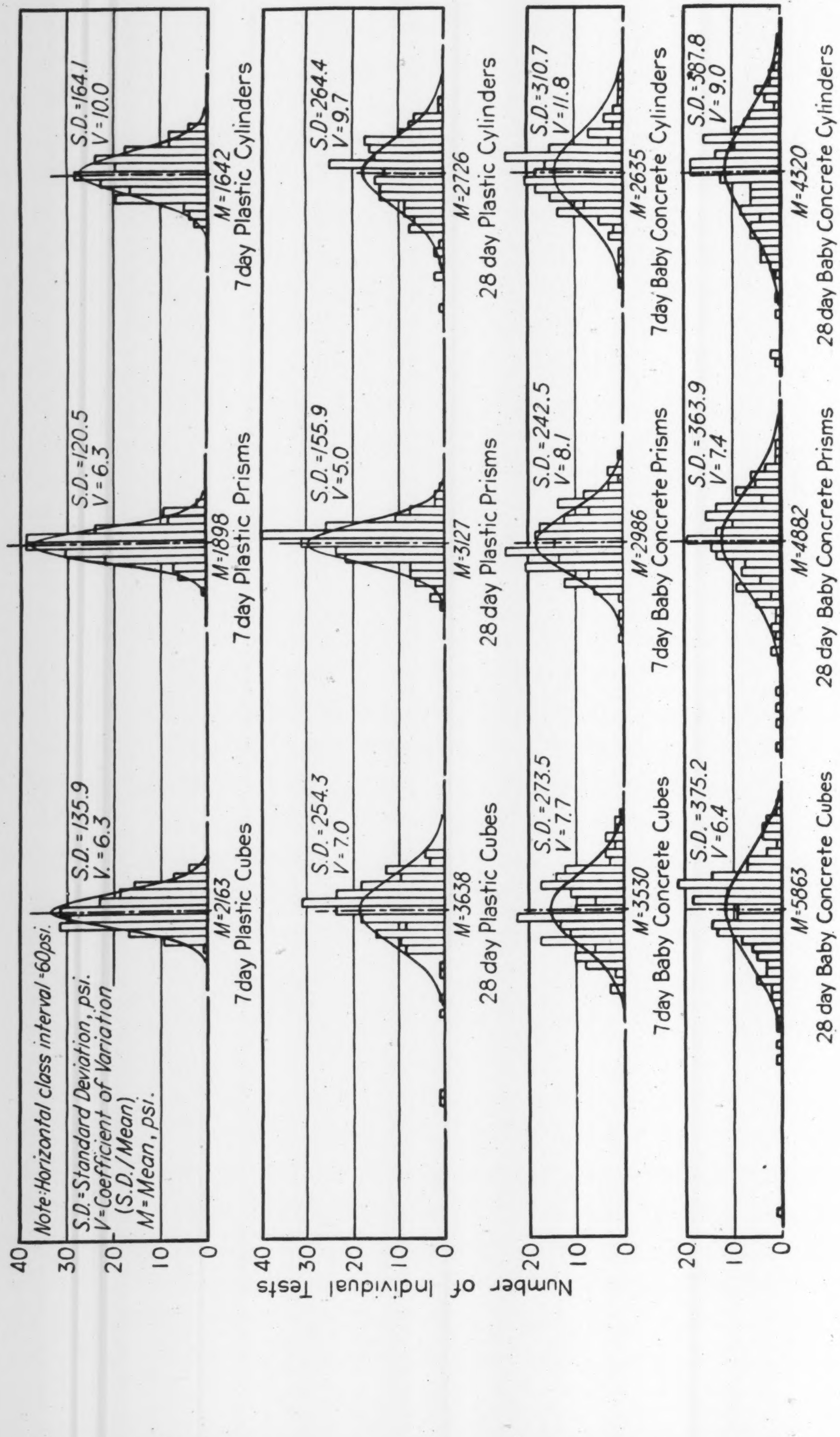

FIG. 1.—Study of 7 and 28-day Compressive Strength Results.

were taken directly from the storage water before testing.

Series II:

The methods used in series II corresponded exactly with those used in series I. However greater difficulty was found in connection with smoothing off the tops of the specimens made from the "baby concrete" due to the $\frac{3}{8}$-in. pebbles. All tests in series II were made in conjunction with series I. It should be noted that each of the 60 days of work involved the same number of batches for each series.

Series III:

The methods used in series III on the 60 Maine commercial sands were those outlined in A.S.T.M. Method C 87 – 36, with slight revisions as outlined in a letter of March 24, 1938, by F. H. Jackson, Chairman of C-9, to members of Subcommittee IX on Specifications and Methods of Tests of Aggregates. The intent of Jackson's revision was to unify the existing specifications of A.S.T.M., A.A.S.H.O. Method T-71 (M-6), and the Federal Specifications SS-A-281, SS-D-181a and SS-C-158.[13]

The amount of water each sand would absorb was estimated by the Pratt method.[14] In brief, this method utilizes the physical properties of the sand to estimate the amount of water which

TABLE II.—SUMMARY OF TEST RESULTS.

	Mix and Type of Specimen	Number of Specimens	7-Day[a]					28-Day[a]				
			Mean Compressive Strength, psi.	Variation Among All Individuals		Variation Within Daily Batches		Mean Compressive Strength, psi.	Variation Among All Individuals		Variation Within Daily Batches	
				S.D., psi.	V or 100 S.D./Mean	S.D., psi.	V or 100 S.D./Mean		S.D., psi.	V	S.D., psi.	V
SERIES I—C 109 - 37 T MIX (PLASTIC MORTAR)												
60 repeat tests on same materials	Cubes....	360	2163	135.9	6.3	80.5	3.7	3638	254.3	7.0[b]	193.5	5.3
	Prisms...	360	1898	120.5	6.3	91.6	4.8	3127	155.9	5.0[b]	135.4	4.3
	Cylinders.	360	1642	164.1	10.0	110.9	6.7	2726	264.4	9.7[b]	216.5	7.9
SERIES II—PEARSON'S MIX ("BABY CONCRETE")												
60 repeat tests on same materials	Cubes....	360	3530	273.5	7.7	174.1	4.9	5863	375.2	6.4	344.2	5.9
	Prisms...	360	2986	242.5	8.1	176.8	5.9	4882	363.9	7.4	305.5	6.2
	Cylinders.	360	2635	310.7	11.8	211.9	8.0	4320	387.8	9.0	317.4	7.3
SERIES III—COMMERCIAL SAND (C 87 - 36)												
Tests on 60 different Maine sands	Cubes....	360	2846	339	11.9		3.9	4815	453	9.4		3.4
	Prisms...	360	2453	276	11.3		2.9	4275	387	9.1		2.4
	Cylinders.	360	2370	286	12.1		3.8	4106	428	10.4		4.1

[a] *S.D.* = Standard Deviation or the root-mean-square of deviations from the mean.
V = The coefficient of variation expresses the Standard Deviation as a percentage of the mean. This makes possible the comparison of the different standard deviations.

[b] See second reference of footnote 3. Gilkey and Leavitt (Table IX, p. 295) obtained the following comparable values.
V: For cubes 7.2, for prisms 10.0, and for cylinders 8.0.

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[13] Jackson's recommendation for changes in A.S.T.M. standard C 87 – 36:
Section 2.—In Footnote 2 change 359 cc. to 360 ml.
Change the third sentence to read as follows: A sample of sand of known weight[2] which has been placed in a saturated surface-dry condition[3] by means of the procedure specified in Section 3 of A.S.T.M. tentative standard C 128 – 36 T shall be, etc.
Insert footnote 3 reading as follows: If the absorption as determined by A.S.T.M. Tentative Standard C 128 – 36 T is known, sand may be prepared for test by adding to a known weight of dry sand the amount of water it will absorb, and permitting the sand to stand in a covered pan for 30 min. before use.
Section 3.—Insert after first sentence: The flow table with the attached shaft shall weigh 9 ± 1 lb. The frame of the table shall be attached rigidly to a concrete pedestal which in turn is attached rigidly to the floor. The concrete pedestal shall be at least 8 in. in diameter and 25 in. in height and shall weigh at least 100 lb.

[14] H. A. Pratt, "A Quick Method for Estimating the Absorption of Fine Aggregate," *Bulletin No. 35* Maine Technology Experiment Station (1939).

would be absorbed by the given sand. A series of tests were made upon 60 different sands according to A.S.T.M. Tentative Method C 128 – 36 T.

The curing and testing of the specimens in series III were *identical* with those of the two previous series. It should be noted that in series III 60 different types of sands were involved, whereas in each of the former series only one type of material was examined. The laboratory work on this series was performed between June 23 and November 2, 1938.

INTERPRETATION OF RESULTS

A study of the 7 and 28-day compressive strength results on each type of specimen was made for each of the three series. Some of the results are shown graphically in Fig. 1, and a summary of the results for all three series of tests is given in Table II. The frequencies shown in Fig. 1 give a picture of the spread or variation of the results from the means of the series. Even a casual observer will note that the spread or distance of the extreme results from the mean of the series in each case is noticeably large. One unfamiliar with data of this kind might expect to get results which would not spread to any such degree as shown in this figure. In fact, a closer agreement of daily results would be expected because in series I and in series II the materials were identical throughout the 60 repeat tests, laboratory temperatures, moisture and all details affecting the mixing and curing periods being kept as constant as possible. However, this extreme spread has been noted in former studies, and further discussion of this phase of the investigation is given later in this report.

One of the primary objects of this study was to evaluate the testing characteristics of the three forms of specimens. At the present time, many testing engineers prefer the 2-in. cube to the standard 2 by 4-in. cylinder. Professor Gilkey has for several years investigated the properties of the 2 by 2 by 4-in. prism.[3] It was hoped, therefore, that this study might develop facts leading to the choice of one of these forms of test specimens.

Reference to Table II indicates that in both series I and II for the 7-day tests the value of the coefficient of variation V is less (indicating better concordance) for the cubes than it is for the prisms or for the cylinders. For the 28-day tests of series I, the coefficients of variation indicate slightly less variation for prisms than for cubes or cylinders. This is true both for the variation among all the 180 specimens and for the variation among the three specimens of each daily batch. In series II, the 28-day coefficients of variation indicate that the cubes are slightly superior to prisms and cylinders as regards the variation both among all the individuals and within the daily batches. In all cases, the cylinders were found to be the most variable, so that the adoption of either the cube or the prism as a standard type of compression test specimen would be an improvement over the present 2 by 4-in. cylinder.

Table II also presents the data for series III. This series involved 60 different grades of commercial sands of various compressive strengths. It is evident that the strength variations in these sands will be included in the variation among all 180 specimens for each age and type of specimen. Although the data presented do not afford a direct independent measure of these sand effects, it should be clear that the differences in the sands affect the variation between daily batches rather than the variation within the three specimens of each batch. Therefore, the variations within each batch may be compared for each type of specimen.

Such a small number of sands as here represented (60) could not be expected to establish a basic law in regard to the type of test specimen under method C 87 - 36. However, the data are herein presented because they also bear out the conclusions drawn from series I and II, namely, that either the cube or the prism would be an improvement over the cylinder type of compression test specimen. The relatively smaller variations within the daily batches for the C 87 - 36 mixtures may indicate that an improvement in the concordance of the data for the other two types of mixtures might result either from an improvement in the grading or from a change in the consistency of the first two series.

TABLE III.—ANALYSIS OF VARIANCE BETWEEN AND WITHIN BATCHES.

Source of Variation	Degrees of Freedom	Mean Squares			
		7-day Tests		28-day Tests	
		Series I	Series II	Series I	Series II
CUBES					
Tests of same batch	120	6 490	30 305	37 445	118 457
Batches on successive days	59	42 801	165 304	119 974	186 302
Relative ratios, F^a		6.59	5.45	3.20	1.57
PRISMS					
Tests of same batch	120	8 385	31 267	18 335	93 304
Batches on successive days	59	26 983	114 894	36 513	211 921
Relative ratios, F^a		3.22	3.67	2.00	2.27
CYLINDERS					
Tests of same batch	120	12 301	44 892	46 886	100 769
Batches on successive days	59	56 693	201 607	116 776	251 231
Relative ratios, F^a		4.61	4.49	2.49	2.49

[a] Ratio of larger mean square to smaller mean square. 1.44 is significant, 1.65 is highly significant. These values would be expected purely by chance only five times and once, respectively, in one hundred trials (See George W. Snedecor, "Calculation and Interpretation of Analysis of Variance and Covariance," *loc. cit.*).

Another interesting statistical study involving the analysis of variance[15] for the data of series I and II was made. As previously noted in this report, the concordance, or checking ability, of compressive strength results was found to be very poor. In a former report by this same committee[12] it was reported that *laboratory operators seemed to be unable to make comparable batches of plastic mortar on successive days.* Another way of expressing this surprising condition is to state that the compressive strength results on identical mixes of plastic mortar made on successive days varied more than would random samples from a population having a variance of the individual test results. The results of this investigation are presented in Table III.

From Table III it will be noted that the differences indicated by the relative ratio, *F*, are highly significant except in one case (28-day cubes, series II) in which case, however, the value would be termed significant.

The application of the analysis of variance method to these data, therefore, bears out the conclusions obtained in the above-mentioned previous study of plastic mortar cubes.[12] Even though extreme care is exercised in an attempt to use identical materials and methods of fabrication, unaccountable variations between and within daily batches still exist, a fact which indicates a pressing need for the standardization of laboratory materials and techniques in the testing of plastic mortars.

CONCLUSIONS

1. Cubes and prisms gave less variation in their strength results than 2 by

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[15] *Variance*, according to R. A. Fisher, "Statistical Methods for Research Workers," 1933 Edition, Oliver & Boyd, Edinburgh, denotes the square of the standard deviation, that is, $(\text{S.D.})^2$. See also George W. Snedecor, "Calculation and Interpretation of Analysis of Variance and Covariance," pp. 1-96, Collegiate Press, Inc., Ames, Iowa.

4-in. cylinders. Consequently, either the cube or the prism would be preferable as a type of compression test specimen for mortars.

2. In general, the compressive strength results of the cubes had less variation than the corresponding strengths of the prisms for the C 109 - 37 T (plastic mortar) mix and for the Pearson ("baby concrete") mix. Cubes would be preferable as test specimens also for reasons of economy in the use of materials.

3. The prism gave less variation than the cube as a type, or form, of compressive strength test specimen in the case of the C 87 - 36 tests on 60 Maine commercial sands. In accord with the well-established use of a slenderness ratio of 2 for compression test specimens, the prism would also seem to be preferable to the cube.

4. The data seems to indicate that the C 109 - 37 T (plastic mortar) mix is somewhat preferable to the Pearson ("baby concrete") mix as a standard method of test because—

(*a*) The variations in compressive strength results are less (as measured by the coefficient of variation, *V*).

(*b*) The test specimens are more easily fabricated.

5. In accord with the results of former investigations, undesirably large variations in test results occurred, even though laboratory conditions were maintained as nearly constant as possible.

6. Unaccountable variations between and within daily batches were found to exist in these data as well as in former studies, a fact which points to the need of further standardization of laboratory techniques.

DISCUSSION

MR. A. T. GOLDBECK.[1]—I should like to ask whether a variation in the method of capping the cubes, prisms and cylinders has not affected the results. Were the prisms molded on their sides and were they capped in the same way as the cylinders?

MR. H. W. LEAVITT.[2]—No test specimens were capped. The prisms were molded on their sides and tested on the end, and the cubes the same way. I might say that the base plates in all these molds were very carefully kept smooth and oiled. There was one further trouble encountered in connection with the prisms. To those who may start to construct a cheap form for prisms, I might say that we used a steel plate for the base of these prisms; and employing the same oil that we used for the other specimens, we got considerable adhesion. This troubled us quite a bit, and we examined the plate with the microscope and found that, although it appeared smooth to the naked eye, under the microscope it was really quite rough, and we overcame that, before we did any of the work reported in this paper, by rubbing a cake of paraffin wax over the base plate. We got no adhesion whatever after that very simple way of doing away with adhesion.

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[1] Engineering Director, National Crushed Stone Assn., Inc., Washington, D. C.

[2] Secretary, Maine Technology Experiment Station, University of Maine, Orono, Me.

SOME OBSERVATIONS OF THE WATER VAPOR PERMEABILITY OF CONCRETE*[1]

By H. J. Barre[2]

Synopsis

The purpose of this paper is to present briefly the results of some preliminary and simple tests demonstrating the water vapor permeability of concrete. Two methods of test were employed. In one method, small concrete tanks constructed from special precast units were filled with water and subjected to conditions of ordinary room temperatures and humidities. The inside surfaces of some of the tanks were treated with different kinds of paints. The water in the tanks especially in those without treatment disappeared with surprising rapidity, although no liquid moisture was apparent on the surface. A considerable amount was also lost in some of the tanks with waterproofing treatments.

In the other method, concrete specimens 1½ in. in thickness were subjected to a difference in vapor pressures on the two faces of the specimen. The amount of moisture permeating the specimens was condensed on a cold surface and collected. The results show that even high-strength concretes are permeable to water vapor, although it is known that they are impermeable to liquid moisture even under high liquid pressures.

A brief review of water vapor permeability measurements including those of other materials is also given.

The observations presented herewith were made in connection with the initial stages of a study of the accumulation of moisture in fill type insulation (1),[3] particularly as it relates to various types of wall construction and treatments of wall surfaces to make them impermeable to water vapor. The problem of condensation of moisture in walls cannot be studied thoroughly without due consideration of the water vapor permeability of the materials of which the wall is constructed.

Two groups of observations were made: (*a*) observations with concrete tanks, and (*b*) water vapor permeability measurements of concrete specimens. These will be discussed in the order named.

Observations with Small Concrete Tanks

Some preliminary tests with a small tightly covered concrete tank together with other general observations seemed to indicate that water may be lost from a concrete container of this sort although there was no evidence of liquid water appearing anywhere on the outside surface, after apparently all evaporation losses from within the tank had been eliminated. A natural inference seemed to be that the water was lost in the form of vapor which diffused through the concrete. Further verification of such losses was obtained by tests, described below, on small concrete tanks. An additional objective during these tests was to determine the effectiveness of waterproofing treatments in reducing such losses.

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* The presentation of this paper at the annual meeting was sponsored by Committee C-9 on Concrete and Concrete Aggregates.

[1] *Journal Paper No. J 657*, Iowa Agricultural Experiment Station, Ames, Iowa, Project No. 541.

[2] Research Assistant Professor, Agricultural Engineering Section, Iowa Agricultural Experiment Station, Ames, Iowa.

[3] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 865.

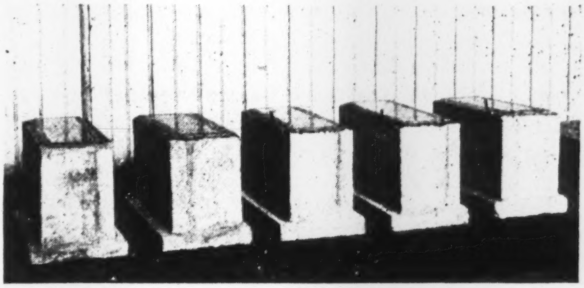

FIG. 1.—The Small Concrete Tanks Under Test.

Description of Tanks:

Each of five small tanks (Figs. 1 and 2) were made by mortaring together two concrete L-blocks, size $4\frac{1}{2}$ by 8 by 16 in., to form a four-wall enclosure. The bottom of the tank was the same kind of concrete as the walls. The thickness of both was $1\frac{1}{2}$ in.

These blocks were cast in steel forms using a concrete mix of 1 part cement, 4 parts sand and $1\frac{1}{2}$ parts pea gravel by volume with a water-cement ratio of 7 gal. per sack. The concrete was machine mixed and vibrated in the forms. The age of the blocks at the time of test was over five months.

The respective tanks were given the following waterproofing treatments:

Tank No. 1.—Only the joints on the inside treated with two coats of liquid coating asphalt.

Tank No. 2.—Two coats of liquid coating asphalt applied over the inside surface.

Tank No. 3.—Two coats of cut-back asphalt applied over the inside surface.

Tank No. 4.—Two coats of aluminum powder in asphaltum applied over the inside surface.

Tank No. 5.—No treatment.

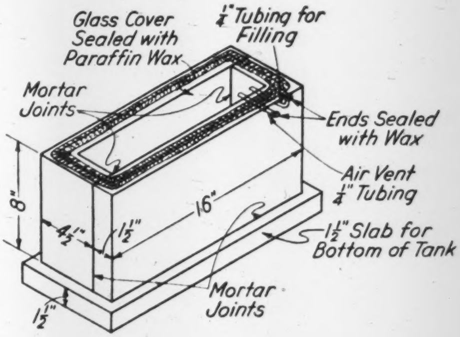

FIG. 2.—Detail of Tank Constructed with Concrete L-Block Units.

Glass covers were sealed in place with paraffin to permit visual inspection of the inside surfaces and the water level. Two $\frac{1}{4}$-in. copper tubes were placed below the cover to permit easy filling of the tanks.

Test Method:

The tanks were placed in a room in which the relative humidity of the air varied from about 30 to 40 per cent and the temperature from 65 to 75 F. The tanks were weighed periodically to determine the loss of water. The openings of the copper tubes were sealed with wax to eliminate evaporation losses through them.

Results:

The amounts of water remaining in the tanks after filling, as determined by the weighings, are presented graphically in Fig. 3. These results show the surprising rate at which water is lost from tank No. 1 and through the waterproofing treatments in tanks Nos. 2 and 3. The treatment with two coats of aluminum paint on tank No. 4 was very effective in reducing the rate of moisture loss. The water in tank No. 5 with no treatment was lost in a very short time due to a leaky mortar joint and the data for this tank are not included.

Although a number of these tanks were losing water at a comparatively rapid rate, there was no evidence anywhere of liquid water on the surface of the tanks except No. 5 and a slight moist condition on part of a mortar joint in No. 3.

WATER VAPOR PERMEABILITY MEASUREMENTS OF CONCRETE SPECIMENS

Brief Review of Permeability Determinations:

Numerous determinations of the permeability of such materials as paint films (4), and wrapping and packaging materials (2) have been made by different investigators. More recently measurements have also been made on building plasters, papers, and boards including moisture-proofing treatments (1, 6), but to date only a few results have been reported. None, however, has been reported on concrete.

The various methods employed and the factors influencing water vapor permeability measurements of materials other than those for building materials have been reviewed by Carson (2) of the National Bureau of Standards. Although the test conditions, procedure, and units of water vapor permeability used vary widely, the methods are relatively few. In all methods the specimen must necessarily be subjected to a difference in vapor pressures, and the amount of water vapor passing through the specimen from the side of the higher to that of the lower vapor pressure measured.

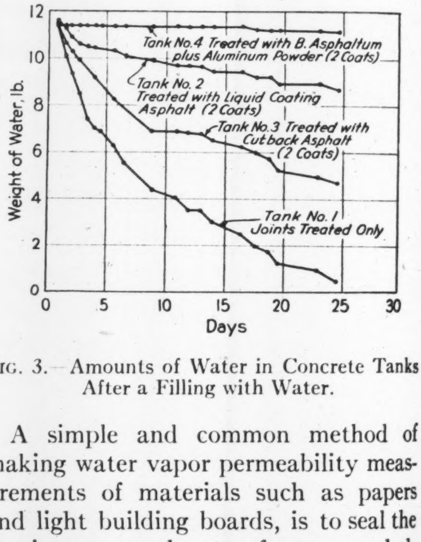

FIG. 3.—Amounts of Water in Concrete Tanks After a Filling with Water.

A simple and common method of making water vapor permeability measurements of materials such as papers and light building boards, is to seal the specimen on to the top of a tray or shallow pan of light metal. Water or some reagent is placed in the pan to give the desired relative humidity or vapor pressure on the lower side of the specimen. The pan with its contents is then usually placed in a constant temperature humidity cabinet or room, to provide a constant vapor pressure on the lower as well as on the upper side of the specimen. The amount of moisture passing through the specimen can be determined by the loss in weight of the pan and its contents. The vapor pressures can readily be determined from the temperatures and relative humidities on

Pagination Error in *Proceedings*

Attention is called to an error in pagination in the 1939 *Proceedings*. In printing, pages 862 and 864 have been interchanged; page 862 has been designated 864, page 864 being designated 862. It is suggested that you make suitable notation of this in your copy of the *Proceedings*.

each side of the specimen from published tables on saturated vapor pressures of water.

The transfer of moisture M through materials has been found within certain range of test conditions, to be proportional to the difference in vapor pressures P, to the area A and time t after steady flow has been established. Hence, the transfer of moisture through a specimen is often given by the relation

$$M = KAPt$$

where K is the coefficient expressing the property of the material for the thickness under consideration, and is usually referred to as the water vapor permeability.

The value K for papers by Charch and Scroggie (3) has been found to vary with the relative humidity on the high-pressure side of the specimen. For relative humidities up to about 75 per cent K was observed to be constant, but for humidities above 75 per cent it was found to be higher, especially for materials of low permeability. A similar variation was also observed in measurements of building boards by the author (1).

There are a number of other variables to be considered in the measurement of water vapor permeability of materials, including time of conditioning to obtain steady flow, edge leakage and variation of the vapor pressure across intervening spaces of still air. For a more detailed discussion of different methods of measurement and the influence of various variables in the determination of water vapor permeability, the appended references should be consulted.

Test Method:

The apparatus used for measuring the water vapor permeability of concrete slabs is shown in Fig. 4. In principle, this method differs from the common method described above, in that the difference in vapor pressures on the two sides of the specimen is created by cooling the funnel shaped condensing surface to a temperature below the dew point of the air above the specimen. The amount of moisture passing through the specimen is collected as condensate in beakers, which can be weighed at desired intervals.

A preliminary test of a 1½-in. concrete specimen by a similar method indicated that appreciable amounts of moisture may pass through concrete with ordinary room conditions above the concrete and a temperature of the condensing surface of 32 F. In this method the condensing surface was in a form of a shallow tray, and the apparatus was so constructed that it was not possible to weigh the condensate until the termination of the test.

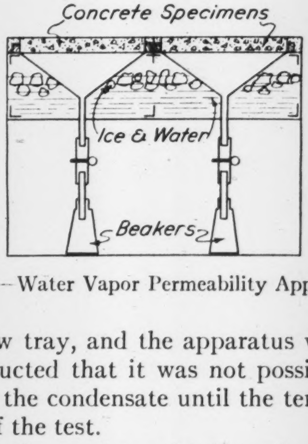

FIG. 4.—Water Vapor Permeability Apparatus.

In order to determine how the water vapor permeability might vary with rather widely varying properties of concrete, 1½ by 10 by 10-in. specimens with the mixes shown in the following table were cast and cured for 28 days under moist conditions:

Specimen	Water-Cement Ratios	
	Gal. per Sack	Parts by Weight
No. 1	5¼	1:3¾
No. 2	9¼	1:7¼
No. 3[a]	5¼	1:4¼
No. 4[a]	9¼	1:8

[a] Pozzuolanic admixture.

The specimens were sealed in the apparatus (Fig. 4) with equal parts of a mixture of melted beeswax and rosin. A constant vapor pressure of 0.214 psi. above the specimen was maintained by placing the apparatus in a constant temperature humidity room at 50 per cent relative humidity and a temperature of 75 F. With the temperature of the condensing surface maintained near 32 F. with a mixture of ice and water, the vapor pressure across the specimen was 0.125 psi. The beakers were weighed at intervals of every day or two during the entire test period of 28 days. Since a small break in the seal of specimen No. 3 developed a few days after the beginning of the test, the results for this specimen were discarded and are therefore not given. A period of about 8 to 10 days appears to be required to establish appreciable flow.

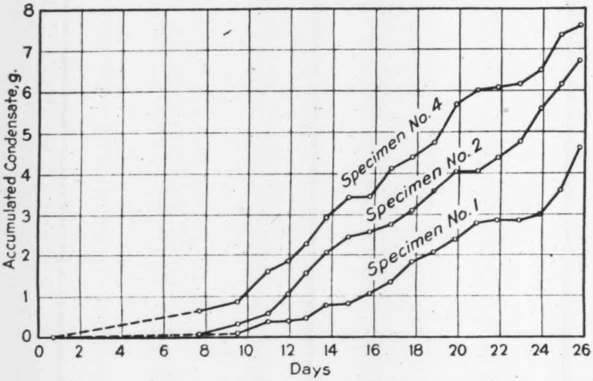

FIG. 5.—Accumulated Amounts of Moisture Transmitted Through Concrete Specimens.

Results:

The accumulated quantities of condensate shown in Fig. 5, indicate that the water vapor permeability of the specimens of different mixes do vary. From an average slope through the observed values of each specimen after flow had been established, the rates at which the moisture passed through the specimens were as follows:

Specimen	Permeability, g. per sq. ft. per hr.
No. 1	0.0156
No. 2	0.0224
No. 4	0.0274

These results indicate that the higher strength mixes as well as those of lower strength are permeable to water vapor, although to less degree, even though they are known to be impermeable to liquid water under high pressure. The nature of the flow of condensate is in all probability responsible for the irregular character of the curves in Fig. 5.

CONCLUSIONS

Moisture losses from untreated surfaces of concrete tanks which emerge in the form of vapor raised the question as to the method by which moisture passed through concrete. The latter tests clearly indicated that the concrete was permeable to water vapor even when no liquid was in contact with the surface. Other correlated tests clearly showed that this same concrete would permit the passage in the amount by the action commonly referred to as capillarity. This series of tests seems to have the value in establishing at least tentatively the magnitude of vapor and capillary resistance of the type tested under conditions of these tests.

Acknowledgments:

The author wishes to express his sincere appreciation to the following for their valuable suggestions and assistance; Dr. J. B. Davidson, Head of the Department of Agricultural Engineering, Prof. W. M. Dunagan of

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the Department of Theoretical and Applied Mechanics and Chairman of Subcommittee VIII, of Committee C-9, and Prof. L. E. Pinney of the Department of Physics, all of whom are at Iowa State College.

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(1) H. J. Barre, "The Relation of Wall Construction to Moisture Accumulation in Fill Type Insulation," Unpublished Thesis, Library, Iowa State College, Ames (1938).

(2) F. T. Carson, "Permeability of Membrances to Water Vapor with Special Reference to Packaging Materials," *Miscellaneous Publication M127*, Nat. Bureau Standards (1937).

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(5) G. M. Kline, "Permeability to Moisture of Synthetic Resin Finishes for Aircraft," *Journal of Research*, Nat. Bureau Standards, Vol. 18, p. 235 (1937).

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METHODS FOR MEASURING THE PASSAGE OF WATER THROUGH CONCRETE*

By W. M. Dunagan[1]

Synopsis

There is a need for correlation of knowledge about the permeability of concrete and how to test this property. Permeability implies fluid passage in liquid form, as capillary-evaporation moisture, and by water vapor movement. This paper presents the beginnings of a correlation of data concerning these methods by which moisture moves through concrete. In it are presented (1) a discussion of permeability, (2) some tests of the same concrete tested for water passage under all three conditions, (3) tests of identical specimens at low heads alone and for capillarity, and (4) a proposed method to compare high-head liquid flow of water to capillarity.

The new information secured by tests in this study is that capillary movement of water through concrete may be of a greater magnitude than that of free liquids at ordinary heads; it is shown that for that reason permeability tests which operate at such heads (less than 10 ft.) measure mostly capillarity. Thus low-head tests may show concrete containing water-repellent materials to be more resistant to capillarity than standard portland cements because their surface tension characteristics have been altered. Such tests do not necessarily measure the ability of these concretes to resist the passage of liquid water. Vapor diffusion treatment contained in this paper and that of H. J. Barre[2] are intended to supplement each other.

The author, as a member of Subcommittee VIII on Permeability Tests of Concrete of the Society's Committee C-9 on Concrete and Concrete Aggregates, accepted the assignment of making a comparison of methods for measuring the permeability of concrete. The present paper is a report on that assignment and represents the status of the investigation as it now stands. Additional information is being secured and will be reported.

It was the intent of C. H. Scholer, former Chairman of Subcommittee VIII, that this group publish a report in which methods for measuring the permeability of concrete be shown and compared. The conclusion was reached, however, that a comparison of equipment for making such tests was of little value unless accompanied by comparative test data from each method of test. No directly comparable test data of this nature were available.

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* The presentation of this paper at the annual meeting was sponsored by Committee C-9 on Concrete and Concrete Aggregates.

[1] Associate Professor of Theoretical and Applied Mechanics, Iowa State College, Ames, Iowa.

[2] See p. 860.

This author began his study by investigating studies made in other fields for analogous situations. He found them to be about as follows:

1. In studies of the flow of free liquid through granular matter such as soils and gravels, considerable information was available. No data were available to compare testing methods nor to contrast materials except in a general manner.

2. Capillary forces have been the subject of extensive study on the part of soil and earth physcists. Some relationships are available in that direction for such inert materials as soils (**6**).[3] It is in these studies that the true magnitude of capillary potential is presented.

3. Vapor movement through structural materials is receiving added attention in recent years because of demands for humidity control. New data are available in that direction and new emphasis is placed upon this phenomenon as a source of moisture movement. Vapor pressure differences demand a place in any consideration of permeability (**7**).

For any condition under which water passes through a given material a general equation may be written between the forces acting and the resulting flow. Such an equation takes into account the fact that the amount of flow of fluids through any permeable medium is a function of three variables: (1) the inherent property of the material to resist flow, (2) the area subject to permeability and (3) the forces tending to produce flow. This relationship is represented by a general equation known as Darcy's law.

(*a*) Stated for the flow of liquids (saturated flow) it may be applied to concrete as was done by Ruettger, Vidal and Wing (**1**)

$$Q = K'A\,\frac{H}{L}\,\ldots\ldots\ldots(1)$$

where Q = discharge quantity, unit volume in unit time,

H = head of fluid,

L = percolation length,

A = gross area subject to percolation, and

K' = permeability coefficient for concrete under consideration.

(*b*) For capillary movement of moisture this same relationship may be stated as was done by Richards (**6**) for soils $q = -K\,\nabla\Phi$, which when expressed in similar terms as above becomes

$$Q = K''\,A\,\nabla\Phi\quad\ldots\ldots\ldots(2)$$

Where $\nabla\Phi$ is the total water-moving field or the total field tending to produce motion of the water, for example the pressure gradient force and gravity.

(*c*) Applied to vapor permeability situations, the formula may be used as was done by Barre (**9**) in the form

$$Q = K'''A\,\frac{dP}{dL}\,\ldots\ldots\ldots(3)$$

where dP is the vapor pressure differential causing vapor movement.

Any adequate summary of the permeability of portland-cement concrete will include a comparison of the three coefficients K. The author took tests of these phenomena from other sources and attempted to correlate them with published test data for portland-cement concrete so as to derive such values. He was compelled to conclude: Laws developed relative to moisture movement for inert materials such as soils or sands cannot be applied directly to portland-cement concretes. Portland-cement concrete has as its fundamental ingredient a material which changes in pore characteristics with each increment of combined moisture (1), and changes in volume with each increment of loss or gain of moisture. The familiar curve showing reduction in flow of liquid water through concrete with time of exposure to water pressure (10) has a logical basis other than such explanations as silting of pores, etc. To vindicate such curves the author made a series of tests as shown in Fig. 1.

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[3] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 879.

The most comprehensive information about permeability to be printed since this study began is that of the Bureau of Reclamation (1). Data from many sources are here assembled and compared. The conclusion is reached that the flow of liquid water through mass concrete follows the normal law of viscous flow:

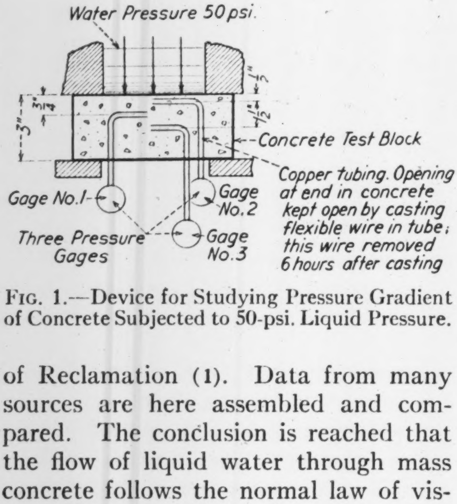

Water Pressure 50 psi.
3"
3/4"
1"
1 1/2"
Concrete Test Block
Copper tubing. Opening at end in concrete kept open by casting flexible wire in tube; this wire removed 6 hours after casting
Gage No. 1
Gage No. 2
Gage No. 3
Three Pressure Gages

FIG. 1.—Device for Studying Pressure Gradient of Concrete Subjected to 50-psi. Liquid Pressure.

$$Q = KA \frac{H}{L} \quad \text{(Darcy)} \ldots\ldots (1)$$

They develop values for K for various conditions, chiefly variations in ratio of water to cement and maximum aggregate sizes.

The test report published by Ruettgers, Vidal, and Wing (1) is a classic work. It will doubtless serve for many years as a basis for estimating the permeability of concrete to liquid (saturated flow) when subjected to great heads. It is this author's opinion that these test results are of great value for the purposes for which they were found, but that the method of test employed could not well be advocated for general use nor the test results applied generally to every day low-head conditions and kinds of concrete.

Since the publication of the foregoing paper others have appeared. Notable is that by Wiley and Coulson (2) and a very competent discussion of it by S. P. Wing (5). With the exception of Wing's discussion, permeability is treated to mean the passage of water in any form through concrete.

Among the problems that make it desirable for a study to be made of permeability tests as to the property which they actually measure is that caused by the practice of adding "water repellents" to portland cement for the purpose of increasing water-tightness. The Bureau of Reclamation tests (1) were made under conditions to promote actual liquid flow of water under great heads for sufficient time to hydrate all cement; lesser heads promote flow which is chiefly that occasioned by capillarity and evaporation. Such tests as those of the Bureau which measure liquid permeability or saturated flow might not be influenced by the presence of a water-repellent; tests made at low heads will be so affected.

These papers, along with some preliminary tests of his own, led the author to the following conclusions:

1. Saturated flow of water through concrete, ordinarily called percolation, is rare, occurring only in weak concretes or under very great heads. Most available studies have not separated such flow from low-head flow which is not in liquid form.

2. Since no data were available in which tests had been made simul-

TABLE I.—SUMMARY OF TESTS MADE TO COMPARE THE PASSAGE OF WATER THROUGH CONCRETE BY VARIOUS MEANS.

Mix	Water-Cement Ratio, gal.	Water, per cent	Special Feature		Strength, 28 days, psi.	Water Passage, ml. per hr. per sq. ft.			
			Aggregate, max.	Paste Type[a]		Liquid at 50 lb., 50-hr. rate	Capillary, no head 500-hr. rate	Water Loss by Box Test, 500-hr. rate	Vapor Diffusion Rate (Barre)
No. 1	5.25	0.21	¾	1	4360	0.	0.54	0.50	0.0156
No. 2	9.25	0.21	¾	1	1800	0.65	1.10	1.40	0.0224
No. 3	5.25	0.19	¾	3	4950	0.	0.20	0.35	X
No. 4	9.25	0.19	¾	3	2260	0.13	0.60	1.25	0.03247
No. 5	5.25	0.21	¾	2	5890	0	0.15	0.30	Not run
No. 6	9.25	0.21	¾	2	3110	0	0.85	1.60	
No. 7	5.25	0.19	¾	4	6040	0	0.20	0.40	
No. 8	9.25	0.19	¾	4	3350	0	0.43	1.10	
No. 9	7.2	0.21	¾	2	4350	0	0.85	1.20	
No. 10	6.6	0.205	¾	5	4200	0	0.35	0.40	
No. 11	7.2	0.19	¾	4	4770	0	0.65	0.90	
No. 12	6.6	0.19	¾	6	3980	0	0.22	0.25	
Tests on mixes 13 to 29 are given in Table II. For comparison with these data use the rate for period No. 5									
No. 41	6.6	0.18	¾	1	2555	0.10	0.60	Not run	
No. 42	6.6	0.21	⅜		3250	0.05	0.70		
No. 43	5.7	0.16	¾		4050	0	0.35		
No. 44	5.9	0.19	⅜		3500	0	0.09		
No. 45	9.1	0.18	¾		1500	Heavy	1.1		
No. 46	5.6	0.18	¾		3300	0	0.20		
No. 47	4.7	0.18	¾		4750	0	0.10		
No. 48	9.1	0.18	⅜		1500	Heavy	1.0		
No. 49	5.6	0.22	⅜		3900	0	0.10		
No. 50	4.6	0.22	⅜		5400	0	0.08		

[a] 1 = Standard portland cement used.
2 = High-strength portland cement used.
3 = Pozzolith added to standard cement.
4 = Pozzolith added to high-strength cement.
5 = Cement used contains a water repellent.
6 = Water repellent cement plus pozzolith.

TABLE II.—PERMEABILITY TESTS OF CONCRETE AT LOW HEADS.

The data are plotted in Fig. 7.

Mix	Water-Cement Ratio, gal.	Aggregate, maximum size	Strength, 28 days, psi.	Water Passage, ml. per hr. per sq. ft.[b]							
				Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
				No head	2-ft. head	No head	2-ft. head	No head	2-ft. head	No head	2-ft. head
No. 13	10	1½	1580	2.6	2.1	1.2	1.1	1.0	0.85	0.5	X
No. 16[a]	10	1½	1505	2.5	1.3	1.6	1.1	0.7	0.95	0.8	1.0
No. 14	10	¾	1605	2.4	1.5	1.5	1.1	1.0	0.8	X	X
No. 17[a]	10	¾	1565	4.2	2.2	2.1	1.3	1.0	1.2	0.6	0.5
No. 15	10	⅜	1450	4.8	3.0	2.0	3.0	1.3	2.5	0.8	0.85
No. 18[a]	10	⅜	1500	5.0	2.4	2.3	1.4	1.5	0.8	0.8	X
No. 20	7¼	¾	3640	1.1	0.30	0.8	0.4	0.1	0.6	0.4	X
No. 23[a]	7¼	¾	3580	1.8	0.05	0.17	0.35	0.05	X	0.13	X
No. 10[a]	5½	1½	3790	0.8	0.55	0.6	0.2	0.01	0.3	0.01	X
No. 8	5½	¾	4530	0.6	0.60	X	X	X	X	X	X
No. 11[a]	5½	¾	4300	0.2	0.10	0.6	0.33	0.05	0.07	0.05	X
No. 12[a]	5½	⅜	4250	0.2	0.25	0.35	0.05	X	0.05	X	X
No. 26	4½	¾	5600	0.55	0.38	0.15	0.1	X	0.05	0.15	0.03
No. 29[a]	4½	¾	6030	0.05	0.05	0.15	0.02	X	0.30	0.27	X

[a] Indicates the use of pozzolith, an admixture to reduce the water required in the mix.

[b] X indicates faulty test. Wax seal could not withstand more than a 2-ft. head for long period of time.

taneously of the same concrete for these characteristics, it was necessary for the author to make such tests as his facilities would permit in order to arrive at some definite values for such characteristics as "capillary" movement of water and resistance to vapor diffusion.

In consequence of these conclusions a large number of tests were made. Not all are included here. Those reported may be divided into three groups:

1. Twelve concretes in which specimens were tested to "correlate properties" (mixes 1 to 12, Table I). These were tested (*a*) for permeability by a box test, (*b*) for capillarity by a pan test, (*c*) for liquid permeability at 50-lb. pressure, and (*d*) mixes 1 to 4 for resistance to vapor diffusion (H. J. Barre (**9**)).

2. A series (mixes 41 to 50, Table I) in which the effect of aggregate size, the relationship between cut and cast specimens, the thickness of specimens and other factors was studied in relationship to capillarity.

3. Mixes 20 to 29, Table II, were prepared to demonstrate the effect of capillarity as compared to a 2-ft. head. At the same time, aggregate size, water-cement ratio and the effect of a water-reducing agent "pozzolith" were observed.

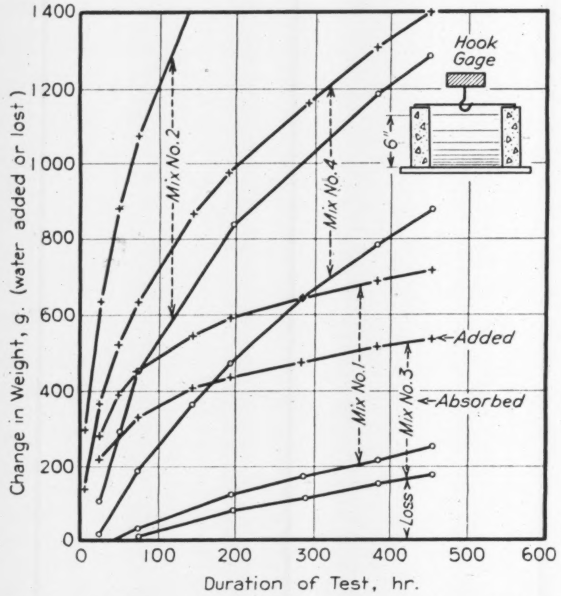


FIG. 2.—Complete "Box Test" Record from Tests of Four Concretes (Mixes 1 to 4, Table I).

Upper curve in each case is water added to the box.
Lower curve is water lost from the box.
Difference between curves is water absorbed.

TESTS MADE

1. *Tests to Investigate Pressure Gradient:*

Several concrete specimens were mounted with tubes embedded as shown in Fig. 1. A pressure of 50 lb. was applied at the surface with pressure gages at the depths indicated. The behavior of the pressures may be generalized as follows: In the case of concretes having a strength above 3000 psi.

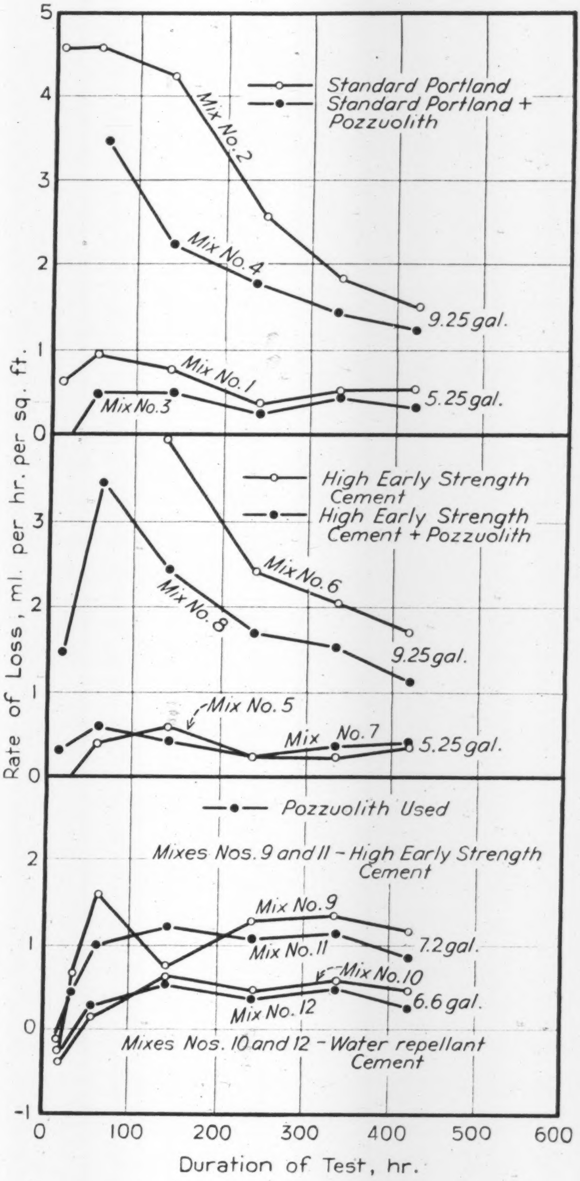


FIG. 3.—Water Loss Through Sides of Box in Box Test.

no pressure reached gage No. 1 ($\frac{3}{4}$-in. embedment); for a concrete of strength about 2000 psi. gage No. 1 reached a maximum of 26 psi. in about 24 hr. and then began to recede. It was impossible to again obtain more than 15 psi. (without drying the specimen and retesting it). When the 50-psi. pressure was released from the surface, the 15-psi. pressure on cell No. 2 maintained itself for a long period of time as though the concrete were "pumped up" like a football. (This pressure remained until the specimen was permitted to dry out.) These tests seemed to bear out two conclusions: (1) The flow of liquid water through concrete will be at a reducing rate as water reaches the grains of cement and hydrates them. (2) Constants for flow of liquid water through concrete can be developed only for a condition in which all of the cement has been hydrated, which means that water has percolated entirely through the con-

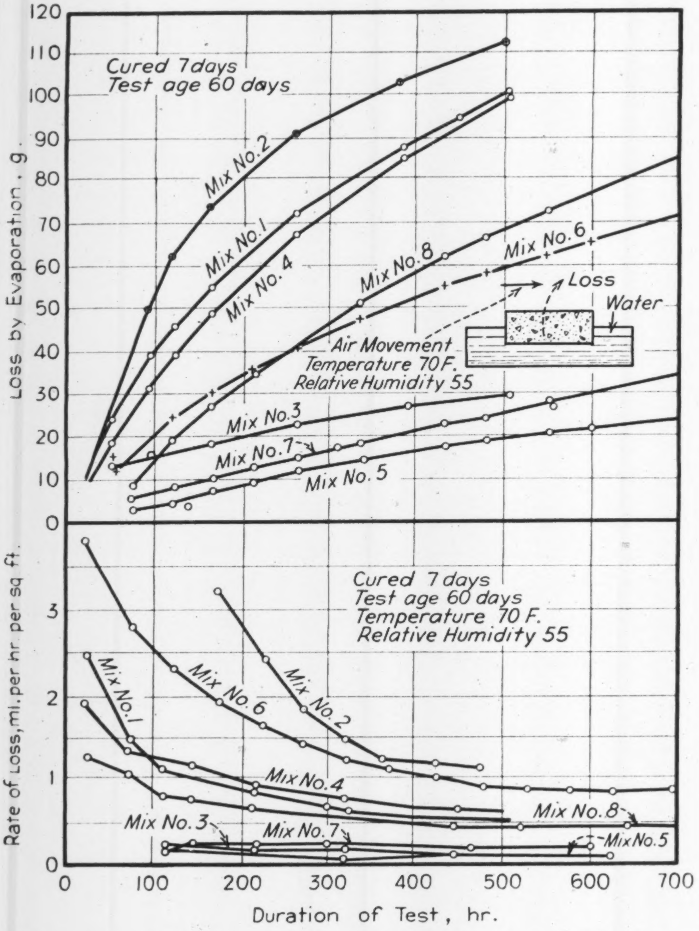


FIG. 4.—Complete "Pan Test" Record of Capillary-Evaporation Test.

crete for a sufficient period of time to do this, a period varying with the kind and amount of cement present.

Several tests similar to the foregoing were performed. It is regretted that they did not lend themselves to presentation in the form of quantitative data or in graphic form.

2. *Tests by Use of Box Method:*

H. J. Barre (9) reports a series of tests in which he studied one aspect of permeability by the use of a box composed of two L-shaped blocks. In his preliminary tests Barre studied only the effect of various materials as waterproofing agents upon the water resistance of the sides of the box. Since he used only one quality of concrete, the author repeated his tests using twelve different kinds of concrete (see mixes 1 to 12, Table I). For this series, Barre's test method was revised to include a hook gage within the box so that the water could be maintained at a constant level.

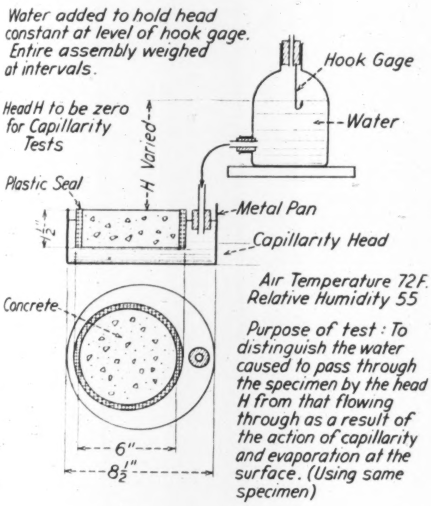

Water added to hold head constant at level of hook gage. Entire assembly weighed at intervals.
Hook Gage
Head H to be zero for Capillarity Tests
H Varied
Water
Plastic Seal
Metal Pan
1½"
Capillarity Head
Air Temperature 72F. Relative Humidity 55
Concrete
Purpose of test: To distinguish the water caused to pass through the specimen by the head H from that flowing through as a result of the action of capillarity and evaporation at the surface. (Using same specimen)
6"
8½"

FIG. 5.—Equipment Used in Tests for Capillarity and for Low Head Flow Study.

Pan only used to test for capillarity.
See Figs. 4 and 12.
Head from bottle added for tests shown in Fig. 7.

These new boxes were made by clamping the blocks together and sealing all connections with wax. They were then placed on rigid metal plates and all except 1 sq. ft. of interior and exterior surface was painted with aluminum paint. The water necessary to maintain the level was recorded and the entire assembly weighed at intervals. Figure 2 is a complete record of such a test; Fig. 3 is the rate of water loss only from the box for all of the concretes tested by this method.

It will be noted that the rate of loss decreases with time to a constant rate at about 500 hr. Water was lost from all boxes regardless of the quality of concrete. The box wall thickness was 1½ in. the same as that used for all other permeability tests.

3. *Capillarity Tests of First Series:*

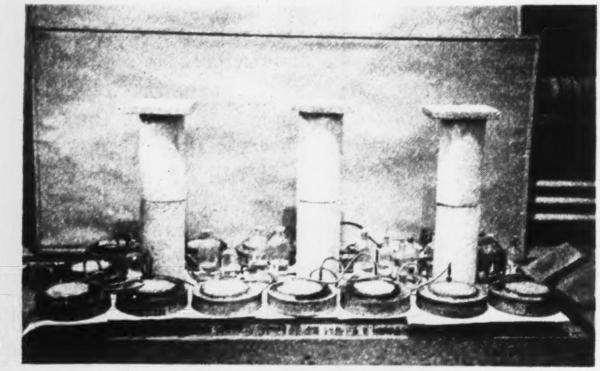
Disks 6 in. in diameter, 1½ in. thick, were made of this same concrete. They were tested for capillarity by a pan test in which the specimen is under no head (see Fig. 5 for pan used). There was a consistently greater loss from the box than from the disks with concrete from the same mix and same thickness (Table I). It was because of this difference in moisture loss that the author attempted to determine the effects of low heads upon concrete as compared to capillary loss only.

These later tests indicated that this difference was due to other causes such as curing or placing differences or even of imperceptible leakage from the box.

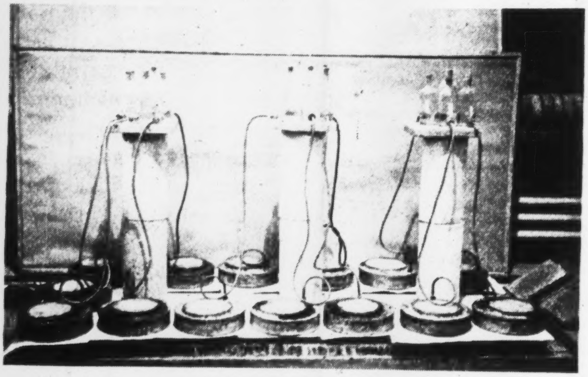
4. *Capillarity Compared to Low Head Flow (2-ft. head):*

Fourteen concrete disks were placed in devices such as that of Fig. 5, and tested for a long period of time. The tests were alternated between no head (capillarity) and 2-ft. head. A small fan kept air movement over the surfaces to insure normal evaporation. Complete results are tabulated in Table II and plotted in Fig. 7.

It was clearly shown that any losses resulting from the application of 2-ft. head could not be detected by this device. Some specimen holders were imperfect so that edge leaks developed, but in the majority of tests no increase in flow was noted when heads were increased. In several cases actual decreases in rate of loss was noted with each application of the 2-ft. head. This will be left unexplained but was noted in several cases; it may be due to increased water of absorption.



(*a*) No static head. Arrangement such that all water passing through the concrete does so because of the forces of capillarity and evaporation.



(*b*) 2-ft. static head. In this situation the water passing through the concrete does so because of the combined force of capillarity, evaporation and of the 2-ft. head.

FIG. 6.—Comparison of Two Methods for Testing the Watertightness of Concrete.

Disks 1½ in. thick by 6 in. in diameter were sealed into metal pans. The samples were exposed to alternate tests for capillary action alone and to capillary action plus the controlled static head. It was hoped by this method to distinguish between the capillary characteristics of the concrete and its permeability to liquid water at such heads.

5. *Test of Slices Sawed from Cast Concrete:*

Some 6 by 12-in. cylinders of these concretes were sawed into slices and the pieces tested for their permeability. No consistent difference could be detected in the resistence of cut disks and of cast concrete disks when subjected to 50-lb. pressure. In both cases, only the concrete of less than 2700 psi. strength permitted the passage of liquid water

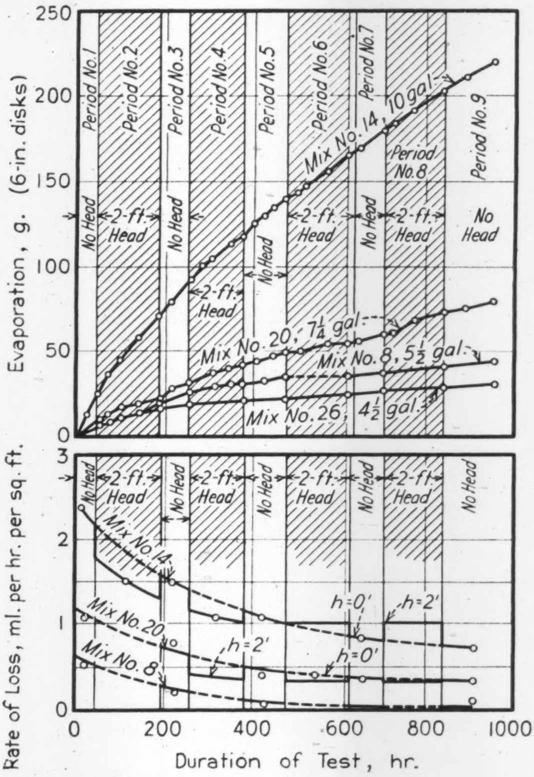


FIG. 7.—Permeability Tests of 1½ in. Thick Disks Exposed to Alternate "0" and 2-ft. Heads.

For additional tests see Table II.
Specimen No. 14 shows tendency to permit greater loss.
Tests in air of laboratory in normal conditions of temperature and humidity.

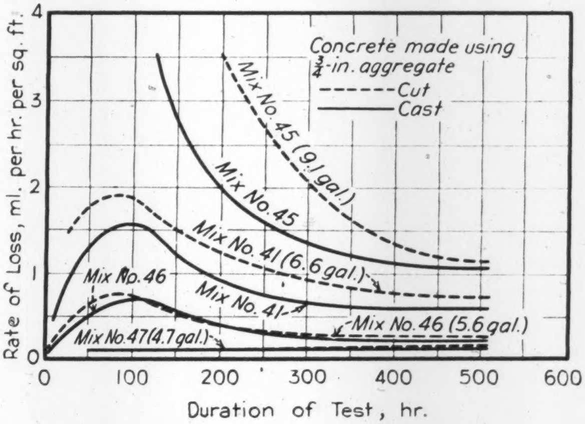


FIG. 8.—Capillarity by Pan Test (See Fig. 5).

1½-in. cast disks compared to disks sawed from 6 by 12-in. cylinders of the same concrete.

under 50-lb. pressure. However, in many cases the disk cut from the top 1½ in. of a 6 by 12-in. cylinder was quite "permeable," containing channels through which the pressure caused the water to flow freely. This seems to be a characteristic of the top inch of concrete cylinders placed with more than 2 or 3-in. slump. The channels are probably due to the upward displacement of water (ordinarily called "bleeding"). Such open channels carry large amount of water under pressure. However, they do not seem to affect the capillarity. This may be one reason why capillarity test results are more uniform than those for liquid flow of water.

The test results shown in Fig. 8 indicate that a disk sawed from a cylinder will show less capillary water passage than one cast of the same concrete. This may be due to the fact that the evaporation surface of a sawed slice is plane whereas a trowelled surface is rough and presents more area for evaporation. This result is in direct contrast to those of Ruettgers, Vidal and Wing (1) which indicate a "surface effect," causing a reduction of liquid flow for cast specimens.

6. *Tests of the Effect of Thickness of Specimen upon Capillarity:*

Slices 1½ in. thick and 4 in. thick were sawed from the 6 by 12-in. cylinders. In four cases the 4 in. thick specimen was tested for capillarity in comparison with a 1½-in. specimen. In each case the rate of leakage at 200 hr. for both thicknesses was nearly identical. However, at 500 hr. the 4 in. thick specimen lost water at a lower rate (see Fig. 9).

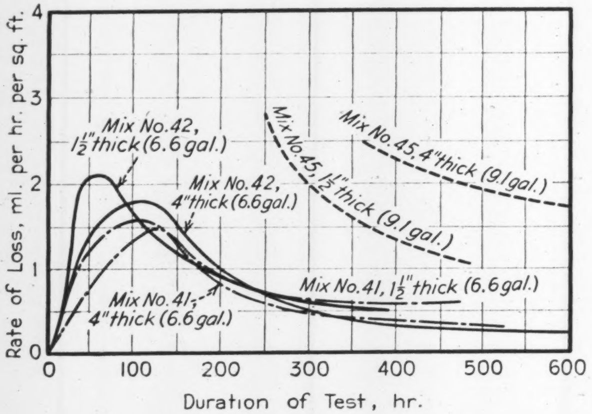


FIG. 9.—Capillarity by Pan Test (See Fig. 5).

Effect of thickness of specimens sawed from 6 by 12-in. cylinders of dimensions shown.

7. *Test to Compare High-head Liquid Flow with Capillarity:*

Since it is shown by Ruettgers (1) that under certain conditions the flow of water through concrete did follow the law of viscous flow (1) and in this paper it is shown that it does not follow this law at low heads, this author made an attempt to discover where this divergence begins.

A test was made using the device shown in Fig. 10. This is a modification of a method proposed by Cloyd M. Chapman (8). Chapman's scheme is here modified to include a method for applying internal pressure to desired amounts and a method for measuring variations in this pressure.

Two specimens were cast as shown in Fig. 10. In each the cavity was filled with water and they were exposed to the air of the laboratory and weight losses recorded at intervals of time. With one specimen a force was applied to the plunger until the gage reached a desired amount; the packing nut was then firmly tightened and a record kept of the time-pressure relationships on the gage. With the other specimen no pressure was applied.

TYPICAL RECORD.

Concrete quality: 6 gal. per bag, $\frac{3}{4}$-in. gravel aggregate.

Duration of test, hr	0	5	10	15	20	30	48[a]	48	60
Gage reading, psi	200	35	22	20	16	15	15	0	15
Weight loss	Weight losses identical in both specimens.								

[a] At this point the pressure was released, the packing nut retightened and the test continued. With no additional application of force the gage again assumed a pressure of 15 psi. Such pressure evidently came from that "stored up" in the concrete from the original pressure. This seems to indicate that no water movement was occurring below a pressure of 15 psi., consequently the system was not following the normal law of viscous flow.

The indications of these tests are that a given concrete will sustain some maximum water pressure without permitting the flow of liquid water, in this case 15 psi., but as this pressure is exceeded flow will progress according to some form of Darey's Eq. 1. Since this maximum will depend upon the hydration of the cement particles, such a test will require a long time for completion. Such tests are still in progress.

8. *Tests of the Same Concrete for Liquid Flow and Vapor Diffusion:*

As indicated by remarks elsewhere in this paper and shown in Table I, four concretes were tested for resistance to the liquid flow of water and to vapor diffusion. The vapor diffusion study was made by H. J. Barre (9). A presentation of the results of the study is made by the use of Fig. 11. It will be observed that the liquid flow under 50-lb. pressure followed the usual reducing rate of flow, reaching an approximately constant rate at about 50 hours, while a much longer period was necessary in order to promote vapor diffusion through these $1\frac{1}{2}$ in. thick specimens. Moisture was not collected on the cold side of the specimens tested for vapor resistance until a lapse of 200 hr. and after this period it seemed to appear at a constant rate.

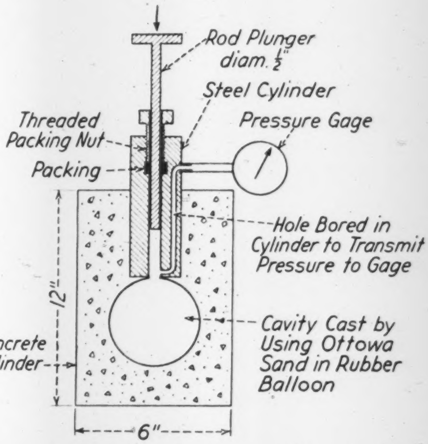


FIG. 10.—Device for Comparing High Head Flow with Capillary Losses Using Same Specimen.

Pressure applied by plunger and losses recorded over period of time.
Pressure varied and losses noted for equivalent periods.

CONCLUSIONS

1. Since present literature contains no cross references to correlate the properties (*a*) liquid percolation, (*b*) capillary action, and (*c*) vapor diffusion, more data are necessary before adequate conclusions can be reached relative to testing the permeability of concrete. An adequate comparison of methods of test cannot be made without a comparison of fundamental data secured by each method. Because of this lack the

reconnaisance tests of this study were made.

2. The presence of water repellents in portland cement causes a reduction in capillary movement of moisture through concrete. This may be explained as for other materials by the reduction of surface tension (**4**). Tests such as the box tests of this paper or other low-head tests will indicate such concrete to be more impermeable than concrete of the same strength without the added water repellent. (In her article on waterproofing Margaret Dana (**4**) says "Waterproofing is no more nor less than a treatment which raises the natural energy of a fabric to the point at which it at least equals the tension of an invading liquid. Then the fabric in a sense calls "Halt" to the invasion of the liquid to any degree whatever. Water-repellent processes, on the other hand, raise the surface tension of a fabric to some degree, and the amount of resistance a cloth has to wetting will depend upon the degree of tension secured.")

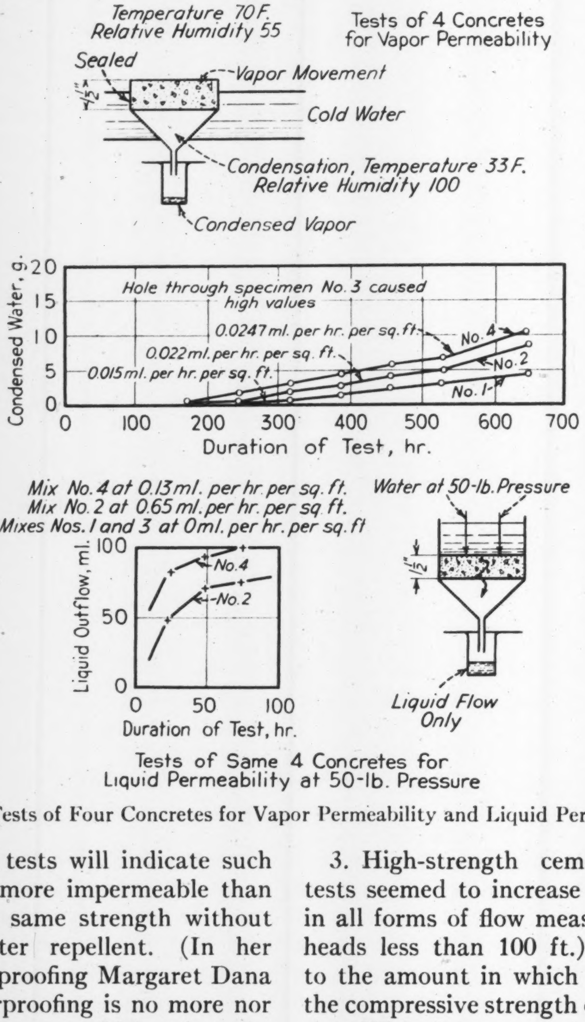


FIG. 11.—Tests of Four Concretes for Vapor Permeability and Liquid Permeability.

3. High-strength cements in these tests seemed to increase watertightness in all forms of flow measurement (with heads less than 100 ft.) in proportion to the amount in which they increased the compressive strength of the concrete.

4. With the same water-cement ratio, a change in the water percentage (space occupied by water at the time of mixing)

by the use of water-reducing agents or by varying the aggregate characteristics will have little effect upon watertightness when measured by low-head (liquid) flow. This leakage varies with the strength of the concrete. In the tests shown herein, a commercial admixture "pozzolith" permitted a reduction in mixing water; this permitted a reduction in cement content for the same strength. An improvement was noted in the capillary resistance of the concrete containing the pozzolith (even at the same strength) (see Fig. 12); this might be explained by assuming that this material contained a water repellent. (An assumption found to be erroneous after the preparation of this paper.)

5. As a method of test for permeability to liquid water, low-head pressures applied to concrete specimens do not measure their leakage characteristics but indicate resistance to capillary movement. In the average usable concrete under average evaporation conditions, capillary movement of water far exceeds the amount of water caused to progress through the concrete by an applied static head.

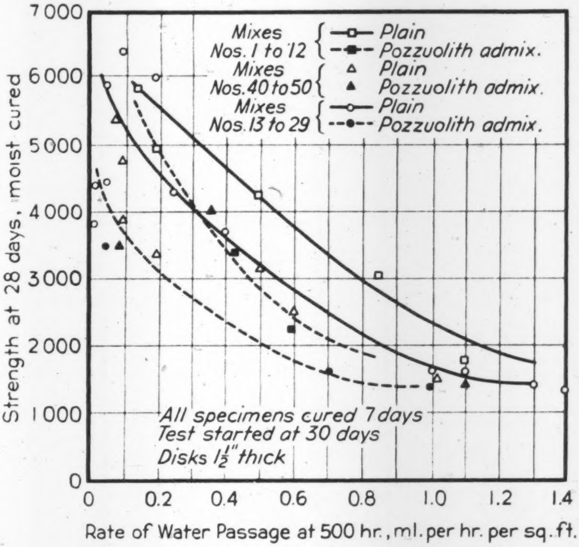


FIG. 12.—Plotted Summary of Capillarity Tests (See Pan Test Fig. 5).

Relationship between 28-day strength and rate of water loss at 500 hr.

Since all tests were made from concrete of plastic consistency, these data indicate an improvement in resistance to capillary movement of water with increase in strength. Pozzuolith, used because it reduced water requirement, made an added improvement.

REFERENCES

(1) Arthur Ruettgers, E. N. Vidal and S. P. Wing, "An Investigation of the Permeability of Mass Concrete with Particular Reference to Boulder Dam," *Journal*, Am. Concrete Inst., Vol. 31, March–April, 1935, p. 382.

(2) George Wiley and D. C. Coulson, "A Simple Test for Water Permeability of Concrete," *Journal*, Am. Concrete Inst., Vol. 34, September-October, 1937, p. 65.

(3) J. C. Pearson, "Low Head Permeability, Test of Mortar Pots," *Jour-*

nal, Am. Concrete Inst., Vol. 35, February, 1939, p. 285.

(4) Margaret Dana, "What Do You Know About Waterproofs?" *Atlantic Monthly*, Vol. 161, January, 1938, p. 86.

(5) Discussion by S. P. Wing of paper by George Wiley and D. C. Coulson, "A Simple Test for Water Permeability of Concrete," *Journal*, Am. Concrete Inst., Vol. 34, January, 1938, p. 76-1.

(6) L. A. Richards, "Capillary Conduction of Liquids Through Porous Mediums," *Physics*, Vol. I, No. 5 (1931).

(7) M. L. Carr, R. A. Miller, Leighton Orr and David Shore, "A Study of Heat Requirements of a Single Glazed Test House and a Double Glazed Test House," *Journal of Heating, Piping and Air Conditioning*, Vol. 10, November, 1938, pp. 745-750.

(8) Cloyd M. Chapman, "New Permeability Specimens for Comparison Tests," *Engineering News-Record*, Vol. 107, July 2, 1931, p. 9.

(9) H. J. Barre, "Some Observations of the Water Vapor Permeability of Concrete," see p. 860.

(10) W. M. Dunagan and G. C. Ernst, "A Study of the Permeability of a Few Integrally Waterproofed Concretes," *Proceedings*, Am. Soc. Testing Mats. Vol. 34, Part I, p. 383 (1934).

DISCUSSION

MR. M. O. WITHEY.[1]—This is an admirable piece of work that is reported upon in this paper. There is just one matter that strikes me as questionable, and that is the relation of permeability to strength. We have had nearly every property of concrete related to its strength, but I hope that before he finishes Mr. Dunagan will be able to relate his findings to other physical characteristics of the material. For instance, he says that there was no relation between flow or vapor transmitted to density. Was there any relation of the leakage or vapor transmission to $\frac{c}{1-\rho}$, the cement void ratio? I think it is proper to show these relationships to strength, but we are often led to misinterpret them. Hence, it is advisable to find other relations if they exist.

MR. W. M. DUNAGAN[2] (*author's closure by letter*).—It was because of my agreement with Mr. Withey's reasoning that my tests tabulated in Table I, were organized as they were. The third column of this table indicates the percentage of water required to bring each of the mixes used to the same workability; since these mixes were at the same workability and since they are compared at the same water-cement ratios, the cement contents and densities (amounts of solid present) will be found to vary with this water requirement. The water required for mixes Nos. 1 and 2 (0.21) is more than that for Nos. 3 and 4 (0.19) because a water reducing agent "Pozzolith" was used in the latter. The water required for No. 41 (0.18) is less than that for No. 42 (0.21) because the aggregate maximum size was changed from $\frac{3}{4}$ in. to $\frac{3}{8}$ in. The author chose these two methods for securing concretes having the same water-cement ratios but varying in densities hoping for some significant information. Careful interpretation of the strength and watertightness data led to the following significant conclusion: regardless of the method used to alter the water requirement of these mixes the strength varied with the water-cement ratio for mixes using similar cements and the resistance to the passage of water in all forms varied with the same variable. For this reason the watertightness was not shown in its relationship to density since such a correlation would have been a duplication.

Despite other attempted correlations a consistent relationship was shown between strength and watertightness as measured by these methods. All data relative to the mixes are available in Tables I and II; if density comparisons are desired they may be easily deduced if it is realized that the water percentage given in the third column is a significant figure.

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[1] Professor of Mechanics, University of Wisconsin, Madison, Wis.

[2] Associate Professor of Theoretical and Applied Mechanics, Iowa State College, Ames, Iowa.

MODIFIED PROCEDURE FOR TESTING CONCRETE AGGREGATE SOUNDNESS BY USE OF MAGNESIUM SULFATE*

By Charles E. Wuerpel[1]

The program of tests conducted in the Central Concrete Laboratory[2] on methods of testing the soundness of concrete aggregate by means of a crystallization test[3] resulted in the formulation of a method of test which provides numerous improvements over the present A.S.T.M. Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 – 37 T).[4] The modified method is appended to this paper.[5]

The departures from the present tentative method are so great that Committee C-9 on Concrete and Concrete Aggregates suggested its publication as information pending opportunity for study of the results obtained from a proposed cooperative series of tests on various methods of testing the soundness of aggregate.

The advantage of the modified method of test lies in the improved concordance of results obtained by its use. A brief discussion of the principal modified features of the method and the reasons for their adoption are given below.

The method is restricted to the use of only one salt, magnesium sulfate, with the elimination of sodium sulfate, because no advantage could be found in having two mediums of crystallization under one test procedure. Magnesium sulfate was chosen because of its lesser sensitivity to temperature change, greater severity of attack, ease of acquisition and cheapness in cost. No compensatory disadvantages are known.

Figure 1 shows the solubility curve of magnesium sulfate and sodium sulfate. The low solubility and great thermal sensitivity of sodium sulfate are obvious.

The scope of the method has been revised in the interests of standardization and in order to eliminate the nullifying effect of the phrase "... the test method should not be used as an arbitrary basis of rejection; it should be used only to furnish information to indicate whether or not the materials *require further investigation of their soundness*" (the italics are the author's). What other *investigations* does this phrase contemplate? The scope in its present form raises the method to the dignity of an acceptance method.

Provision is made for a standard type of specimen container. One of the greatest sources of variables in the existing method is the absence of a container and immersion tank specification. The note to Section 2(*c*)[6] further vitiates the existing method.

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* The presentation of this paper at the annual meeting was sponsored by Committee C-9 on Concrete and Concrete Aggregates.

[1] Engineer in Charge, Central Concrete Laboratory, U. S. Military Academy, West Point, N. Y.

[2] North Atlantic Division, U. S. Engineer Department.

[3] Charles Wuerpel, "Factors Affecting the Testing of Concrete Aggregate Durability," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 327 (1938).

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 804 (1937); also 1937 Book of A.S.T.M. Tentative Standards, p. 645.

[5] See p. 885.

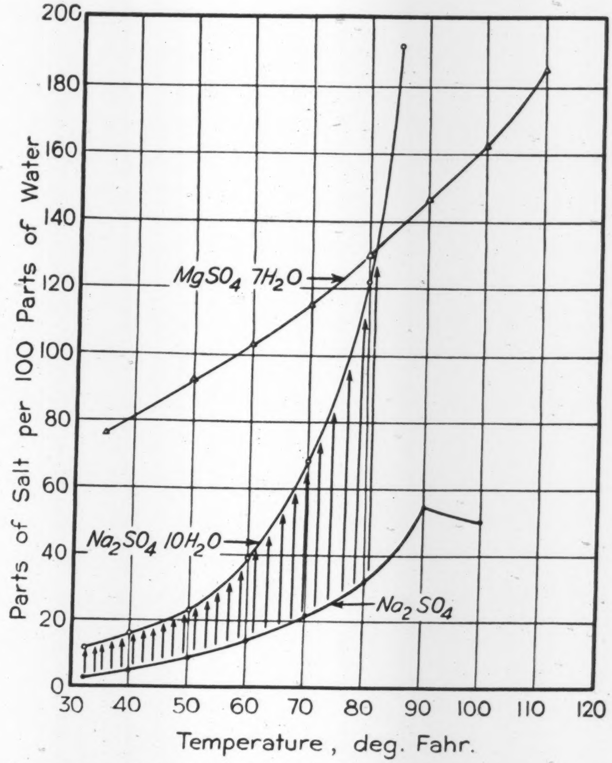

FIG. 1.—Comparison of the Solubility of Sodium and Magnesium Sulfate in Water.

The principle of the test method is changed from a *saturated* solution to a solution of *constant salt concentration.* The latter is preferable because it may be readily achieved, whereas a saturated solution is very difficult to maintain from cycle to cycle of the test. The use of a solution of constant concentration minimizes the effect of moderate laboratory temperature fluctuation upon the results of the test and minimizes the possibility of specimen cementation or "caking" during the progress of the test. In short, it reduces extraneous variables to a minimum.

The results obtained are lower in percentage of specimen weight loss when the less-than-saturated constant concentration solution is used than are obtained with the so-called saturated solution, but the action of the salt crystallization is restricted to the interior of the specimen, where it belongs, and results of repeated tests are more concordant.

The use of centrifugal force is introduced in the removal of excess solution from the samples of fine aggregate. This is done to minimize the tendency toward cementation of the sample by salts precipitated on the surfaces of the particles during the repeated drying cycles. The amount of centrifugal force permitted by the test method is limited to preclude the expulsion of solution from the capillaries of the specimen particles.

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[6] "NOTE.—No standard form of container is recommended since different practices will be most convenient in various laboratories..."

There has been some criticism of magnesium sulfate on the basis that it will react with calcareous materials and thereby introduce an undesired chemical action in the test. Studies conducted in this laboratory indicate that magnesium sulfate will react with some insoluble calcium compounds to an appreciable degree at elevated temperatures, but the extent of the reaction is negligible under the conditions of this test method. The period during each cycle of the test during which the salt is chemically active is so short that the physical results are not appreciably affected.

APPENDIX

PROPOSED METHOD OF TEST FOR SOUNDNESS OF AGGREGATES BY USE OF MAGNESIUM SULFATE

Scope

1. This method describes the procedure to be followed in testing aggregates to determine their resistance to disintegration by an aqueous solution of magnesium sulfate. It furnishes information helpful in judging the soundness of aggregates subjected to weathering action, when dependable service records of the materials are not available. In view of the delicacy of the test it is important that the procedure be followed exactly.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Sieves.*—Sieves with square openings of the following sizes conforming to the Standard Specifications for Sieves for Testing Purposes (A.S.T.M. Designation: E 11) of the American Society for Testing Materials,[1] for sieving the samples in accordance with Sections 4 and 5:

Fine Series	Coarse Series
No. 100 (149 micron)	⅜ in.
No. 50 (297 micron)	½ in.
No. 30 (590 micron)	¾ in.
No. 16 (1190 micron)	1 in.
No. 8 (2380 micron)	1½ in.
No. 4 (4760 micron)	2 in.
	2½ in.

(*b*) *Containers.*—Containers, for immersing the divided samples of aggregate in the solution, consisting of wire-mesh baskets[2] of any desired shape, but of a size at least sufficient to hold the sample with not less than ¾ in. clear distance from the top of the inundated sample to the top of the basket. The meshes of each basket shall be as follows:

Basket	Grain Size of Sample
FINE AGGREGATE	
8-mesh	No. 4 (4760-micron)
16-mesh	No. 8 (2380-micron)
30-mesh	No. 16 (1190-micron)
50-mesh	No. 30 (590-micron)
100-mesh	No. 50 (297-micron)
100-mesh	No. 100 (149-micron)
COARSE AGGREGATE	
4-mesh	any size

(*c*) *Immersion Tanks.*—Suitable tanks for holding the magnesium sulfate solution in which the divided samples of aggregate are suspended during the immersion period. The tanks may be of any desired shape and constructed of any material not susceptible to action by magnesium sulfate, but the size of the tank shall be sufficient to accommodate the amount of solution specified in Section 6 (Note).

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1289 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1607.

[2] Copper or brass wire-mesh baskets are recommended for fine aggregate and galvanized-iron wire-mesh baskets for coarse aggregate.

NOTE.—Separate immersion tanks are recommended for fine and coarse aggregate since the container size for the two will be quite different.

(*d*) *Balances.*—Balances of appropriate capacities shall be provided for weighing the separate grain-size samples before and after testing. The balances shall be accurate to 0.02 per cent of their capacity.

(*e*) *Drying Oven.*—The drying oven shall provide a free circulation of air through the oven and shall be capable of maintaining a temperature of 105 to 110 C. (221 to 230 F.).

NOTE.—A large size oven may be inexpensively constructed of sheet metal lined with asbestos board; the heating provided by ordinary strip heaters, and temperature controlled by bimetallic thermostats.

(*f*) *Reagent.*—Supply of a saturated solution of c.p. barium chloride (see Section 9 (*a*)).

Magnesium Sulfate Solution

3. (*a*) The aqueous solution shall be prepared by dissolving a U.S.P. or equal grade of crystalline magnesium sulfate ($MgSO_4 \cdot 7H_2O$) (Epsom salts) in water at a temperature of 15 to 27 C. (60 to 80 F.) in the proportions necessary to bring the solution to a specific gravity of 1.275 at 21 C. (70 F.) (Note). The mixture shall be thoroughly stirred during the addition of the salt and the solution shall be stirred at frequent intervals for 3 hr. and permitted to stand overnight at a temperature of not less than 15 C., before its initial use.

NOTE.—This mixture requires 1 part of U.S.P. salt to 1 part of water by weight and is a saturated solution at 14 C. (57 F.)

(*b*) The aqueous solution shall be maintained within the temperature range of 15 to 27 C. (60 to 80 F.) throughout the period of the test.

(*c*) The specific gravity of the solution shall be checked with a satisfactory hydrometer (range 1.150 to 1.350) before each sample immersion period. The specific gravity of the solution shall be maintained during the test between 1.265 and 1.285 by additions of water or salt, as required.

Samples

4. (*a*) *Fine Aggregate.*—Fine aggregate for the test shall be passed through a ⅜-in. sieve. The sample shall be of such size that it will yield not less than 100 g. of each of the following sizes, which shall be available in amounts of 5 per cent or more, expressed in terms of the following sieves:

Retained on Sieve	Passing Sieve
No. 100 (149-micron)	No. 50 (297-micron)
No. 50 (297-micron)	No. 30 (590-micron)
No. 30 (590-micron)	No. 16 (1190-micron)
No. 16 (1190-micron)	No. 8 (2380-micron)
No. 8 (2380-micron)	No. 4 (4760-micron)
No. 4 (4760-micron)	⅜-in.

(*b*) *Coarse Aggregate.*—Coarse aggregate for the test shall consist of material from which the sizes finer than the No. 4 (4760-micron) sieve have been removed. The sample shall be of such a size that it will yield not less than the following amounts of the different sizes (Note), which shall be available in amounts of 5 per cent or more:

Size (Square-Hole Sieves)		
No. 4 to ⅜ in.		100 g.
⅜ to ¾ in.	⅜ to ½ in.	1000 g.
	½ to ¾ in.	1000 g.
¾ to 1½ in.	¾ to 1 in.	1000 g.
	1 to 1½ in.	1000 g.
1½ to 2½ in.	1½ to 2 in.	1500 g.
	2 to 2½ in.	1500 g.

NOTE. When coarse aggregate consists of heterogeneous glacial or alluvial gravels the amounts used for the different sizes should be the maximum practicable in order to minimize errors due to nonrepresentation.

(*c*) Should the samples contain less than 5 per cent of any of the sizes specified in Paragraph (*a*) or (*b*), that sizes shall not be tested, but, for the purpose of calculating the test results, it shall be considered to have the same loss in magnesium sulfate treatment as the average of the next smaller and the next larger size, or if one of these sizes is absent, it shall be considered to have the same loss as the next larger or next smaller size, whichever is present. Gravel pebble sizes larger than 2½ in. shall be treated in the manner described for ledge rock (see Section 5 (*c*)).

Preparation of Test Sample

5. (*a*) *Fine Aggregate.*—The sample of fine aggregate shall be thoroughly washed on a No. 100 (149-micron) sieve, dried to constant weight at 105 to 110 C. (221 to 230 F.), and separated into the different sizes by sieving, as follows:

Make a rough separation of the graded sample by means of a nest of the standard sieves specified in Section 4 (*a*). From the fractions obtained in this manner, select samples of sufficient size to yield 100 g. after sieving to refusal (Note). (In general, a 110-g. sample will be sufficient.) Fine aggregate sticking in the meshes of the sieves shall not be used in preparing the samples. Samples consisting of 100 g. shall be weighed out of each of the separated fractions after final sieving and placed in separate containers for the test.

(*b*) *Coarse Aggregate.*—The sample of coarse aggregate shall be thoroughly washed and dried to constant weight at 105 to 110 C. (221 to 230 F.), and shall be separated into the different sizes prescribed in Section 4 (*b*) by sieving to refusal (Note). The proper weight of sample for each fraction shall be weighed out and placed in separate containers for the test. In the case of fractions coarser than the ¾-in. sieve, the number of particles shall be counted.

NOTE.—"Refusal" shall be considered reached when not more than 0.1 per cent by weight passes the particular sieve in 1 min. of continuous shaking.

(*c*) *Ledge Rock.*—For testing ledge rock or pebbles of gravel larger than 2½ in., the sample shall be prepared by breaking it into fragments reasonably uniform in size and shape and weighing approximately 100 g. each. The test sample shall weigh 5000 g. ± 2 per cent. The sample shall be thoroughly washed and dried previous to test as described in Paragraph (*b*).

Storage of Samples in Solution

6. The samples shall be immersed in the prepared solution of magnesium sulfate for 16 hr. in such a manner that the solution covers the material to a depth of at least ½ in. Each sample shall be immersed in a volume of solution sufficient to keep the volume ratio of solution to sample not less than 5 to 1 for coarse aggregate and not less than 7.5 to 1 for fine aggregate (Note).

NOTE.—The maintaining of a definite volume ratio prevents the precipitated salts on the surface of the dehydrated aggregate particles from increasing the specific gravity of the solution by more than 0.005 when they are dissolved.

Drying Samples After Immersion

7. (*a*) *Fine Aggregate.*—After the 16-hr. immersion period the baskets containing fine aggregate shall be removed from the immersion tank and permitted to drain for about 10 min. but not more than 1 hr. After draining they shall be spun centrifugally (Note 1) until the solution is essentially removed from the sample (Note 2). The sample shall then be placed in the drying oven for 6 hr. The temperature of the oven shall have been brought previously to 105 to 110 C. (221 to 230 F.). After the drying period the samples shall be removed from the oven and permitted to cool to room temperature for approximately 1 hr., when they shall be again immersed in the prepared solution as described in Section 6. Care shall be used to avoid the loss of aggregate particles during the various phases of the test.

Note 1.—The centripetal acceleration exerted by centrifugal spinning shall not exceed 5500 ft. per sec. per sec.

Centripetal acceleration may be calculated as follows:

$$A = \frac{V^2}{R}$$

where:

A = centripetal acceleration in feet per second per second,
V = peripheral speed in feet per second, and
R = radius in feet.

Equivalent acceleration may be calculated as follows:

$$\text{Revolutions per minute} = \frac{687}{\sqrt{R}}$$

where:

R = effective radius in feet.

Note 2.—No particular means of obtaining the centrifugal force application is specified. This may be accomplished by various types of centrifuges, slings, or other improvised means. However, it is important that the fine aggregate contain not more than 4 per cent solution in the form of free moisture by weight when the sample is introduced into the drying oven.

(*b*) *Coarse Aggregate.*—After the 16-hr. immersion period the baskets containing coarse aggregate shall be removed from the immersion tank and permitted to drain for about 10 min. and then placed in the drying oven. The temperature of the oven shall have been brought previously to 105 to 110 C. (221 to 230 F.). Care shall be exercised to avoid loss of any of the aggregate particles coarser than the No. 4 sieve. The samples shall be dried for 6 hr. at the specified temperature. After drying, the samples shall be allowed to cool to room temperature, when they shall be again immersed in the prepared solution as described in Section 6.

Cycles

8. The process of alternate immersion and drying shall be repeated until the required number of cycles is obtained.

Quantitative Examination

9. The quantitative examination (Note) shall be made as follows:

(*a*) After the completion of the final cycle, and after the sample is cooled, the sample shall be washed free from the magnesium sulfate as determined by the reaction of the wash water with barium chloride ($BaCl_2$).

(*b*) After the magnesium sulfate solution has been removed, each fraction of the sample shall be dried to constant weight at 105 to 110 C. (221 to 230 F.); weighed; and, except in the case of ledge rock, sieved over the same sieve on which it was retained before the test. The particles retained on this sieve shall be weighed, and the weight recorded.

Note.—In addition to performing the operations described in Paragraphs (*a*) and (*b*), it is suggested that additional information of value will be obtained by examining each fraction visually in order to determine whether there is any evidence of excessive splitting of the grains.

(*c*) In the case of ledge rock the loss in weight shall be determined by subtracting from the original weight of the sample the final weight of all fragments which have not broken into three or more pieces.

Qualitative Examination

10. (*a*) The qualitative examination and record shall consist of two parts: (*1*) Observation of the effect of the action (Note) by the magnesium sulfate solution and the nature of the action upon the portion of the sample retained after final sieving at the end of the test, and (*2*) counting of the number of particles affected.

Note.—Many types of action may be expected. In general, they may be classified as disintegration, splitting, crumbling, cracking, flaking, etc.

While only particles larger than the ¾-in.

size are required to be examined qualitatively, it is recommended that examination of the smaller sizes be made in order to determine whether there is any evidence of excessive splitting.

Report

11. The report shall include the following (Note):

(*a*) Weight of each fraction of each sample before test.

(*b*) Except in the case of ledge rock, material from each fraction of the sample, finer than the sieve on which the fraction was retained before test, expressed as a percentage by weight of the fraction.

(*c*) Weighted average calculated from the percentage of loss for each fraction, based on the grading of the sample as received for examination, or preferably, on the average grading of the material from that portion of the supply of which the sample is representative.

(*d*) In the case of particles coarser than ¾ in. before test:

- (*1*) Number of particles in each fraction before test, and
- (*2*) Number of particles affected, classified as to number disintegrating, splitting, crumbling, cracking, flaking, etc.

(*e*) In the case of ledge rock:

- (*1*) The percentage of loss calculated as described in Section 9 (*c*), and
- (*2*) The number of pieces affected, classified as to number disintegrating, splitting, crumbling, cracking, flaking, etc.

NOTE.—Table I, shown with test values inserted for purpose of illustration, is a suggested form for recording test data.

Reproducibility of Results

12. The results of duplicate tests made in the same laboratory should agree within 20 per cent of the percentage loss for both fine and coarse aggregate.

TABLE I.—SUGGESTED FORM FOR RECORDING TEST DATA.

Sieve Size		Grading of Original Sample, per cent	Weight of Test Fractions Before Test, g.	Percentage Passing Finer Sieve After Test (Actual per cent Loss)	Weighted Average (Corrected per cent Loss)
Passing	Retained on				
SOUNDNESS TEST OF FINE AGGREGATE					
No. 100 (149-micron)		5.0	...	...	...
No. 50 (297-micron)	No. 100 (149-micron)	11.4	100	3.5	0.40
No. 30 (590-micron)	No. 50 (297-micron)	26.0	100	4.2	1.09
No. 16 (1190-micron)	No. 30 (590-micron)	25.2	100	4.8	1.21
No. 8 (2380-micron)	No. 16 (1190-micron)	17.0	100	8.0	1.36
No. 4 (4760-micron)	No. 8 (2380-micron)	10.8	100	11.2	1.21
⅜ in.	No. 4 (4760-micron)	4.6	...	11.2[a]	0.52
Totals		100.0	500	...	5.79
SOUNDNESS TEST OF COARSE AGGREGATE					
2½ in.	1½ in.	20.0	3000[b]	4.8	0.96
1½ in.	¾ in.	45.0	2000[b]	8.0	3.60
¾ in.	⅜ in.	23.0	2000[b]	9.6	2.20
⅜ in.	No. 4 (4760-micron)	12.0	100[b]	11.2	1.34
Totals		100.0	7100	...	8.10

[a] The percentage loss (11.2 per cent) of the next smaller size is used as the percentage loss for this size, since this size contains less than 5 per cent of the original sample as received (see Section 4(*c*)).

[b] Minimum amounts; larger samples may be used.

DISCUSSION

Mr. Ira Paul.[1]—I see two points at issue in the revised method of test for soundness of aggregate proposed by Mr. Wuerpel.

The first is that in the centrifuge method, the author proposes to eliminate the surface salt solution on the aggregate in order to control caking of the samples during the drying cycle. In doing so he is probably unaware of the fact that he is removing the salt solution absorbed by the aggregate. With siliceous aggregates the centrifugal method will not have any appreciable effect on the final test results, because there is very little or no penetration of the salt within the aggregate. However, the method will affect the results on soft and friable aggregates. Not only is the surface solution removed, but some of the absorbed salt solution as well. As a result, lower test values are obtained on questionable or poor aggregates, and in some cases very little or no differentiation can be made between a good and a questionable aggregate.

Secondly, by using a less than saturated solution of magnesium sulfate, a less amount of salt crystals will be absorbed by the aggregate. The activity of the reduced amount of salt crystals will result in correspondingly lower losses or breakdown of a poor aggregate.

Since 1931 the New York State Laboratory, where the magnesium sulfate accelerated soundness test was first developed, has had practically no difficulty in obtaining reproducible tests with the Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (A.S.T.M. Designation: C 88 - 39 T).[2] The 5-cycle test has given us a wide scale of differentiation between good and poor aggregates. Caking of the test fractions after the drying cycle has in no way interfered with the dissolving of the crystals during the immersion period in the saturated magnesium sulfate solution.

Mr. Charles E. Wuerpel[3] (*author's closure by letter*).—The possibility of expulsion of some or all of the absorbed solution from the particles of fine aggregate, during the centrifugal spinning of the specimen baskets, was considered and investigated during the research program[4]. The centripetal acceleration used in the test, and recommended in Note 1 to Section 7(*a*) of the proposed method of test, was found to be insufficient to disturb the solution absorbed by the particles. The centrifugal force is used only to remove the major portion of the *surplus* solution held by surface tension in the voids between the individual particles of aggregate in the test container.

Reference to Table II of the report of the Research Program[4] will indicate that clear differentiation is obtained between good and questionable aggregate when the "centrifuge" method is used. The data shown in Table II are supported by test of fine aggregate from more than 100 sources in the northeastern United States during the past 2 yr.

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[1] Associate Laboratory Engineer, New York State Department of Public Works, Albany, N. Y.

[2] 1939 Book of A.S.T.M. Standards, Part II, p. 98

[3] Engineer in Charge, Central Concrete Laboratory, U. S. Military Academy, West Point, N. Y.

[4] Charles E. Wuerpel, "Factors Affecting the Testing of Concrete Aggregate Durability," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 327 (1938).

The "centrifugal" method using the less-than-saturated solution of magnesium sulfate does produce lower losses than other methods with so-called saturated solutions, but the results are far superior in concordance and, in any case, the percentage of loss is only relative in value.

Prior to the development of the proposed test method, the results of the soundness tests of aggregate varied considerably and were used with some hesitancy by this laboratory as a basis for acceptance or rejection of an aggregate. During the past 2 yr. the new method has been used with confidence and reproducibility.

NEW LABORATORY METHOD FOR DETERMINING THE ORGANIC MATTER IN WASHED FINE AGGREGATES*

By Ira Paul[1]

The Society's Method of Test for Organic Impurities in Sands for Concrete (C 40 – 33)[2] states in its scope: "This test is an approximate method for determining the presence of injurious organic impurities in natural sands which are to be used in cement mortar or concrete. The principal value of this test is to furnish a warning that further tests are necessary before they are approved for use." In other words the Abrams-Harder colorimetric test itself gives no definite information to the testing engineer about organic impurities likely to be present in a fine aggregate which may or may not affect the strength of cement mortar or concrete.

The organic impurities in a fine aggregate, in general, are derived from the decomposition of vegetable matter usually present in the topsoil or stripping of a sand bank. Upon leaching, some of these organic soluble acids and salts of complex nature will percolate through the soil stratum. If the subsoil is of such a nature as to react with these acids or salts, an interchange or direct combination will take place. For example, the organic acids resulting from the decomposition of tree roots, bark, or other vegetable matter will, on percolation through the soil, react with the basic compounds of the sand of alkaline or alkali earth nature to form soluble or insoluble organic compounds as a result of their interaction. Such organic compounds as are soluble in water will usually be removed by a washing process such as a concrete sand is usually given. On the other hand, the insoluble compounds remaining in the aggregate after washing may on further test by the Abrams-Harder method give the typical color reaction. However, physical tests made on such sands for tension, compression, or flexure, provided the sands are properly graded, may show no reduction in strength ratio in the 7 or 28-day period.

The colorimetric caustic soda method is an attempt to measure the amount of organic material in the sand, but it gives no indication as to the nature of the organic matter and its possible activity with cement. In some instances, pronounced dark colored solutions may be obtained in the colorimetric method, yet such sands show no reductions in strength tests. Such color reactions may be due to the solubility of iron salts of complex organic acids in the caustic soda solution. Salts like iron tannate, ferric oxalate, ferric tartrate, etc., when dissolved in caustic soda solution give typical color reactions. The question then resolves itself how is the testing engineer in the laboratory to determine in a relatively short period of time the value of the fine aggregate in so far as organic impurities are concerned by a method other than the physical test.

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* The presentation of this paper at the annual meeting was sponsored by Committee C-9 on Concrete and Concrete Aggregates.

[1] Associate Laboratory Engineer, New York State Department of Public Works, Albany, N. Y.

[2] 1936 Book of A.S.T.M. Standards, Part II, p. 350.

The loss in strength ratio of a fine aggregate that is well graded, structurally sound and one that has been properly washed to remove the required amount of silt and loam may be due to the presence of organic material. In view of the fact that these organic impurities which react with the cement paste are present in relatively small amounts, it is practically impossible to determine these by the ordinary chemical methods. The organic acids present in soils are of a very weak character, incapable of measurement by ordinary extraction or titration methods. These organic acids will react chemically with the lime liberated during the hydration of the cements. To measure this chemical reaction effectively, the hydrogen ion apparatus is very well adapted for use with washed fine aggregate.

The apparatus used for the hydrogen ion determination consists of the usual Leeds & Northrup potentiometer-galvanometer electrical equipment. The galvanometer has a sensitivity of 0.0005 microampere and damping resistance of 10,000 ohms. Its deflections are read by a spot of light, which is thrown by a lamp and scale, and reflected back onto the scale of the same instrument. The use of hydrogen gas is eliminated by the use of a special type of glass electrode dip cell containing quinhydrone. The usual calomel electrode is used as a reference tube. When properly connected and standardized this apparatus covers a range on the scales from 0 to 12.0 pH and is sensitive to values within 0.03 pH.

The glass electrode is the assembly terminating in a bulb as shown in the attached illustrated Fig. 1. It is a measuring electrode, and is used with the ordinary calomel reference electrode, or half-cell, as shown in the illustration. The glass electrode consists of two units. The outer one is the unit that is sensitive to pH changes. The inner unit comprises a mixture of quinhydrone and HCl solution, contained in the bulb and electrically connected to the potentiometer. The calomel electrode is also connected to the potentiometer. Both electrodes dip into the unknown solution. The quinhydrone - HCl solution of course has a definite pH, and is thus a reference unit. The calomel reference electrode also has a definite pH, so that the pH-sensitive glass bulb is immersed in the solution between two reference electrodes. No quinhydrone or other chemical is added to the unknown. Changes in its pH are simply detected by the glass bulb and measured with the potentiometer in the usual way. The electrodes commonly require attention only at intervals of several weeks.

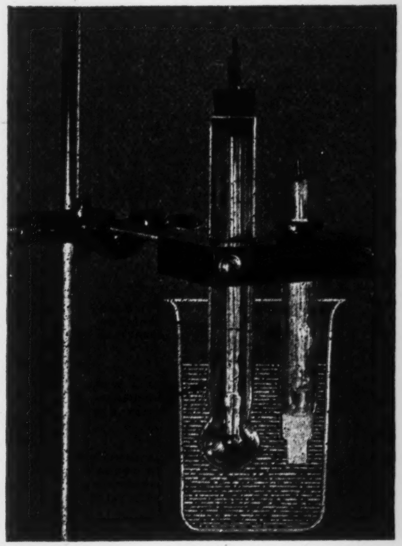
FIG. 1.

The new procedure for determining the organic impurities in fine aggregates is appended.[3]

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[3] See p. 898.

Artificially impregnated standard Ottawa sand was first prepared by adding known quantities of tannic acid to measure the quantitative effect on the pH values, its relation to the physical characteristics on mortar strengths, and the color reactions obtained with 3 per cent caustic soda solution. In the colorimetric test, a scale of colors from 1 to 10 was used instead of the usual A.S.T.M. 5 color scale. This wider range of colors has permitted us to differentiate more closely the color reactions than that given in the present A.S.T.M. method.

TABLE I.—EFFECT OF TANNIC ACID ON 1:3 OTTAWA SAND, 2-IN. MORTAR CUBES.

Tannic Acid, per cent	7-Day Compressive Strength, psi.	Ratio	Color	pH $Ca(OH)_2$ = 12.35	pH Loss
0.......	2525	100	1	12.26	0.09
0.01.......	2569	102	4	12.11	0.22
0.03.......	2069	82	6	11.34	1.01
0.05.......	1919	76	7	10.80	1.55
0.10.......	1481	59	8	7.94	4.41
0.20.......	Disintegrated	0	9	7.16	5.19
0.30.......	Disintegrated	0	10	6.83	5.52
0.40.......	Disintegrated	0	10+	6.63	5.72
0.50.......	Disintegrated	0	10+	6.34	6.01

TABLE II.—EFFECT OF IRON TANNATE ON 1:3 OTTAWA SAND 2-IN. MORTAR CUBES.

Iron Tannate, mg.	7-Day Compressive Strength, psi.	Ratio	Color	pH $Ca(OH)_2$ = 12 08	pH Loss
0.......	2699	100.0	1	11.99	0.09
1.......	2690	100.0	2	11.86	0.13
2.......	2700	100.0	3	11.89	0.10
3.......	2710	100.5	4	11.89	0.10
6.......	2720	101.0	5	11.84	0.15
9.......	2784	103.0	6	11.84	0.15
15.......	2828	105.0	7	11.81	0.18
19.......	3046	113.0	8	11.76	0.23
47.......	2950	109.0	9	11.73	0.35
85.......	2700	100.0	10	11.38	0.70

The results of the tannic acid test on the Ottawa sand indicate that when there is a reduction in pH of 1.0 and over in alkalinity of the limewater solution there is a corresponding increase in the intensity of the color reaction with caustic soda and a reduction in strength ratios.

A study was then made to determine the effect of an iron salt of tannic acid on Ottawa sand. Again the Ottawa sand was impregnated with known quantities of iron tannate and quantitative pH values determined. Tests for color of the sand and strength of mortars were also made.

The results show that the colorimetric effect of iron tannate indicated within the range of colors has very little or no effect on the pH values of the saturated solution of limewater or on the compressive strengths of the standard Ottawa sand mortars.

TABLE III.—EFFECT OF HUMUS ON 1:3 LONG ISLAND SAND MORTARS.

Sample	Tensile Strength				Color	pH $Ca(OH)_2$ = 11.08	pH Loss
	7-Day, psi.	Ratio	28-Day, psi.	Ratio			
A.....	338	100	407	100	1	11.03	0.05
B.....	410	121	515	126	1	11.05	0.03
C.....	297	88	377	92	10	9.38	1.70
D.....	277	82	343	84	9	9.68	1.40
E.....	338	100	447	109	9	10.57	0.43

TABLE IV.—EFFECT OF ORGANIC IMPURITIES IN NATURAL SANDS.

Sample	Compressive Strength Ratios		Color	pH $Ca(OH)_2$ = 12.30	pH Loss
	7-day	28-day			
A..........	133	146	1	12.0	0.30
B..........	112	143	2	11.95	0.35
C..........	127	157	3	11.94	0.36
D..........	136	164	4	11.94	0.36
E..........	114	165	5	11.91	0.39
F..........	117	141	6	11.84	0.46
G..........	139	142	7	11.64	0.66
H..........	135	146	8	11.89	0.41
I..........	108	136	9	11.75	0.55
J..........	110	113	10	11.64	0.66

A further study was then made on the effect of decomposed humus material present in topsoil on a natural quartz sand from Long Island. Three samples of the Long Island sand were impregnated with 4 per cent humus. In sample C the sand was soaked with 4 per cent humus for a period of 7 days

TABLE V.—RESULTS OF TESTS ON COMMERCIAL NATURAL AND ARTIFICIAL FINE AGGREGATES.

Sample	Fineness Modulus	Strength Ratios				Color	pH Loss
		Compression		Tension			
		7-day	28-day	7-day	28-day		
No. 1	3.74	109	133	150	144	1	0.38
No. 2	2.95	108	127	115	133	1	0.44
No. 3	3.42	142	142	143	144	5	0.28
No. 4	3.00	152	122	180	161	1	0.26
No. 5	2.60	123	141	120	104	1	0.18
No. 6	3.38	198	151	138	114	4	0.21
No. 7	3.18	126	128	137	119	2	0.35
No. 8	2.75	140	110	146	132	1	0.38
No. 9	2.77	126	107	126	127	1	0.28
No. 10	3.11	173	160	177	165	1	0.18
No. 11	3.10	133	121	138	122	3	0.28
No. 12	2.30	129	132	116	104	2	0.34
No. 13	3.09	126	126	119	115	1	0.24
No. 14	3.38	123	161	133	126	7	0.28
No. 15	2.79	135	122	125	122	1	0.38
No. 16	3.28	132	175	159	145	2	0.38
No. 17	3.17	126	129	134	151	3	0.29
No. 18	2.89	133	164	139	126	1	0.35
No. 19[a]	2.88	176	164	139	129	1	0.29
No. 20	2.65	103	125	118	100	5	0.15
No. 21[a]	3.02	148	144	118	131	1	0.06
No. 22	3.01	103	115	115	126	4	0.45
No. 23	3.02	183	149	138	160	1	0.34
No. 24	3.27	159	169	135	149	6	0.36
No. 25	2.80	122	134	167	190	1	0.23
No. 26	3.38	127	159	159	136	1	0.14
No. 27	2.73	146	155	138	158	1	0.17
No. 28	2.91	168	165	116	138	1	0.14
No. 29	3.05	149	150	137	165	1	0.17
No. 30	2.75	108	124	123	123	3	0.13
No. 31	2.68	132	121	149	163	2	0.38
No. 32	2.74	152	172	137	137	1	0.23
No. 33	2.57	109	113	108	111	1	0.16
No. 34	2.56	156	142	131	146	1	0.22
No. 35	2.84	142	120	104	119	1	0.18
No. 36	2.65	108	115	122	133	1	0.23
No. 37	2.77	141	133	138	148	1	0.28
No. 38	3.51	148	129	141	149	1	0.13
No. 39	2.74	119	131	104	118	2	0.18
No. 40	3.07	106	128	82	65	9	1.83
No. 41	3.17	138	134	89	70	7	1.07
No. 42	2.78	101	.....	90	.....	8	1.04
No. 43	2.77	116	120	105	123	3	0.31
No. 44	3.02	128	139	105	141	4	0.35
No. 45	3.06	122	118	114	124	4	0.35
No. 46	3.06	110	121	110	110	4	0.35
No. 47	2.56	111	127	103	140	1	0.31
No. 48	2.96	124	126	155	132	2	0.17
No. 49	2.99	143	138	120	134	4	0.27
No. 50	3.19	137	145	145	145	1	0.22
No. 51	2.73	154	143	164	151	1	0.14
No. 52	2.97	148	169	128	150	1	0.19
No. 53	3.09	135	134	142	151	1	0.19
No. 54	2.88	147	152	152	151	2	0.36
No. 55	2.96	134	146	114	135	1	0.28
No. 56	2.81	116	136	126	124	1	0.13
No. 57	3.28	159	153	157	147	1	0.16
No. 58	2.49	138	134	123	118	1	0.18
No. 59	3.15	181	168	142	142	1	0.28
No. 60	3.27	161	184	124	122	4	0.40
No. 61	3.43	206	190	140	127	1	0.22
No. 62	3.62	126	131	136	122	1	0.25
No. 63	2.78	154	148	139	135	2	0.20
No. 64	2.82	178	184	146	135	2	0.25
No. 65	2.52	167	170	125	134	4	0.43
No. 66	2.89	173	168	122	145	1	0.12
No. 67	2.94	164	165	113	124	5	0.26
No. 68	3.17	143	158	123	130	1	0.12
No. 69	3.46	183	180	167	145	1	0.12
No. 70	2.83	137	166	116	116	2	0.23
No. 71	2.61	183	181	131	166	4	0.23
No. 72	2.62	175	189	137	143	4	0.21
No. 73	3.20	165	161	126	140	3	0.31
No. 74	2.87	155	179	134	149	4	0.18
No. 75	3.08	188	154	136	139	5	0.23
No. 76	2.88	152	148	166	145	4	0.48
No. 77	2.71	125	179	134	134	2	0.33
No. 78	3.55	101	124	123	112	3	0.50
No. 79	3.21	180	195	112	119	6	0.25
No. 80	3.04	176	178	124	118	5	0.33
No. 81	3.02	169	138	141	123	6	0.57
No. 82	2.78	114	121	124	114	5	0.40
No. 83	2.91	136	157	140	145	3	0.23
No. 84	2.83	153	122	130	114	6	0.29
No. 85	2.89	102	112	108	107	4	0.81
No. 86	2.92	147	128	128	121	4	0.22
No. 87	3.06	186	143	130	110	7	0.33
No. 88	2.69	112	127	103	100	6	0.65
No. 89	3.78	101	121	90	85	8	1.04
No. 90	3.21	180	195	112	119	6	0.25

[a] Artificial sands.

and then dried. Sample D was impregnated for a period of 24 hr., and in sample E the humus was washed out after soaking for 24 hr. Samples A and B represent the Standard Ottawa sand and untreated Long Island natural quartz sand, respectively. The Long Island sand had a fineness modulus of 3.02.

Again we note that the pH loss in alkalinity of the original limewater solution due to the Ottawa or Long Island sand is practically negligible within the checking accuracy of the test. A loss in strength ratio of mortars due to organic humus material indicated in samples C and D gave a corresponding increase in intensity of color reaction and a reduction in pH value of over one full unit. However, sample E, which had the impregnated humus material washed out, failed to show a reduction in the colometric test, but the loss in pH did check the strength ratios obtained, because the pH reduction was only 0.43 or less than one full unit. The probable reason for a high color in sample E is due to the presence of small pieces of twigs which will react with the caustic soda solution.

A series of tests were then undertaken on natural washed sands found in different sections throughout New York State which showed a similar range of colors in the colometric tests with that obtained in the iron tannate series. The ten samples were regraded so that all had the same fineness modulus of 2.91. These sands were then tested for color by the Abrams-Harder method, pH values recorded with the new method, and compressive strength ratios determined on 2-in. cubes with a 1:3 mix for 7 and 28-day periods.

In Table IV again we note that although these natural sands showed color ranging from 1 to 10 the compressive strength ratios for 7 and 28-day periods showed no strength reduction, and similarly the pH loss in all showed values less than one full unit.

Table V is a tabulation of results of tests over a period of four years on commercial natural and artificial fine aggregates submitted for cement concrete construction work. The fineness modulus, compressive strength and tensile strength ratios, organic color test, and pH values are indicated. It will be noted there is practically no relationship between the Abrams-Harder organic test and the new laboratory test method. Samples numbered 40, 41, 42 and 89, which failed in the strength ratio tests and indicated unsatisfactory color tests, exceeded 1.0 pH loss in accordance with the proposed new test procedure for organic material in sands. Samples Nos. 14 and 87 with unsatisfactory color tests showed low pH losses and satisfactory strength tests. On the basis of organic tests reported in Tables I, II, III, and IV this would indicate that the organic material in samples Nos. 14 and 87 is not reactive with cement, while the organic material present in samples 40, 41, 42 and 89 would cause trouble in the concrete.

The author feels that the proposed new laboratory test method for determining the organic matter in fine aggregates gives the testing engineer a more accurate measurement of the effect of such impurities likely to be present in sands than the Abrams-Harder color test.

In an investigation of some Oregon sands reported by C. E. Thomas and S. H. Graf of the Oregon State College Engineering Experiment Station, in *Bulletin No. 8*, September 1937, the authors recommend the use of the pH method for determining the organic material in sands in preference to the color test.

CONCLUSIONS

1. There is a definite relationship between the new laboratory test method results and the strength ratio tests, provided the sand is properly graded and washed in accordance with the proposed method. Sands passing the strength ratio tests and showing a pH loss of less than 1.0 are indicative of containing non-injurious organic material. When the pH loss is in excess of 1.0 the detrimental effect of organic impurities manifests itself with unsatisfactory strength ratio tests.

2. The gradation or fineness modulus of the sand within the limits of our specification requirements does not affect the results in the pH test, provided the fine aggregate is properly washed.

3. Test results in the new pH method

are not affected by the color of the alkaline solution of limewater.

4. There is no relation between the Abrams-Harder color test and the new pH test.

The advantages claimed in favor of the new test method are as follows:

1. Within a period of 15 min. the laboratory technician can obtain reliable tests indicating the effect of organic impurities in fine aggregates by means of the hydrogen ion apparatus (determined as change in pH of standard lime solution).

2. The personal factor is eliminated, and accuracy is assured. The hydrogen ion apparatus is very sensitive to any chemical change within a working range of 0.03 pH.

3. The apparatus is usually found in any up-to-date chemical control laboratory.

APPENDIX

PROPOSED METHOD OF TEST FOR ORGANIC IMPURITIES IN LABORATORY WASHED SAND BY pH VALUE

1. *Scope.*—This method covers a quantitative test for organic impurities in laboratory washed sand as determined by the loss in pH value of a solution of known pH due to the activity of the organic matter present. The method is only adaptable to sands from which silt and clay have been removed by washing. Its indications are inaccurate when silt and clay are present.

2. *Special Solution Required: Calcium Hydroxide Solution.*—Prepare a fresh, saturated solution of lime water by adding c.p. lime (CaO) to freshly distilled water. Allow the lime to settle for a few minutes, decant a sufficient amount of the clear supernatant $Ca(OH)_2$ solution into a 2-liter flask, and adjust to a pH value between 11.0 and 11.5 by the addition of distilled water.

3. *Preparation of Sample.*—Place a representative sample of sand weighing about 500 g. in a full-height, No. 100 (149-micron) sieve 8 in. in diameter. Wash the sample throughly under the full pressure of tap water, rotating the sieve by hand until the washings are perfectly clear and free from any suspended matter. Dry the sample to constant weight at 105 to 110 C.

4. *Procedure.*—Weigh a 200-g. portion of the thoroughly washed and dried sample into a 250-ml. beaker (Note), and add 150 ml. of the standardized $Ca(OH)_2$ solution. Immediately stir the mixture thoroughly, and allow to stand for 10 min. Again stir the mixture thoroughly and allow to stand for another 5 min. At the end of this 15-min. period, very carefully immerse the two electrodes of the hydrogen ion apparatus in the sample solution, and record the pH value. Simultaneously take an exact pH reading on a 200-ml. portion of the $Ca(OH)_2$ solution to which no sand has been added. The difference between this reading and the reading obtained on the solution containing the sample, represents the loss in pH value due to activity of organic matter present in the sand.

NOTE.—Keep the beakers containing the solutions covered with watch glasses throughout the test.

DISCUSSION

MR. MEYER HIRSCHTHAL.[1]—I believe that a method of test whereby there is additional washing of the sample in the laboratory after the washed sample is presented, presents a danger that in this later washing some material in the sample will be washed out which might affect the pH value and would then not give a clear indication of the soundness of the sample presented. Mr. Paul claims that unless this sample is washed again, you do not get a true indication of what the soundness is, because the pH test fails. Now, there is something wrong with the test when it is necessary to make it in a manner other than that in which the sand will be used, and I think this should be taken into consideration for a modification of the test, whereby any part of the sand that is presented for use in concrete will not be taken out of the sample to be tested.

MR. IRA PAUL[2] (*author's closure by letter*).—If the fine aggregate is properly prepared by the producer, as called for in the N. Y. State Department of Public Works' specification, which states "All natural sands shall be thoroughly washed before using," no additional washing is necessary in the laboratory prior to making the pH test. If sands have to be treated in the laboratory it is clear evidence that they were improperly prepared at the washing plant. This is particularly noticeable in fine aggregates containing an excess of fines in the form of shale or clay.

Water-soluble organic material can be eliminated by proper treatment at the washing plant. After such treatment the pH test can then detect the effect of other organic impurities to a more reliable degree than the Standard Method of Test for Organic Impurities in Sands for Concrete (C 40 – 33).[3]

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[1] Concrete Engineer, D. L. & W. R. R., Hoboken, N. J.

[2] Associate Laboratory Engineer, New York State Department of Public Works, Albany, N. Y.

[3] 1939 Book of A.S.T.M. Standards, Part II, p. 295.

A FLOW METHOD FOR THE DETERMINATION OF THE EFFECTS OF SOLUBLE CHEMICALS ON CONCRETE[1]

By Dalton G. Miller,[2] Charles F. Rogers,[3] and Philip W. Manson[4]

Synopsis

The conclusions of this paper are based on results obtained by allowing weak solutions of acetic and lactic acids to flow across flat slabs of concrete and mortar set nearly vertical (17 deg. departure). In most cases, paraffin dykes restricted the flow of acid to an area 1½ in. wide and 14 in. long. In other cases, laboratory-made bars 2½ by 3 by 15 in. were cast with slightly depressed 1½-in. lengthwise channels. The hydrostatic head on glass capillary tubes was adjusted to deliver to each channel 2 liters of acid every 24 hr. Each channel was brushed with a flat steel brush about the size and shape of a 1-in. paint brush, and the loosened material was caught in filter-paper lined funnels, oven-dried, and weighed.

Concrete with a modulus of rupture from 800 psi. upward displayed resistance to corrosion of weak acids three times that of concrete with a modulus of rupture of 500 psi. under the conditions of exposure used in these tests.

Mortar made of the least resistant of nine standard portland cements yielded a quantity of loosened material 1.6 times that released by mortar made of the most resistant of these nine cements.

Within the range of characteristics of the specimens used in the tests, the acid consumption was surprisingly uniform for all specimens.

The test method as illustrated in Figs. 1 and 2 and described in this paper was devised primarily to facilitate laboratory studies of the durability of portland-cement mortars and concretes exposed in farm silos to the corrosive action of silage. Because acetic and lactic are the common acids of corn silage, these acids were used to approximate the action of corn silage. It is believed that the general features of the test may be satisfactorily adapted for determining the resistance of concretes of various types to corrosive action of many soluble chemicals.

Procedure:

Concrete silo staves made of measured ingredients at two commercial plants and laboratory-made test bars were used. The specimens were set nearly vertical (17 deg. departure). Paraffin dykes were built lengthwise on half staves to confine the acid flow to an area 1½ in. wide and 14 in. long. The bars, which were 3 in. wide and 15 in. long, were cast with recessed panels, and the acid flow was likewise confined to an area 1½ in. wide and 14 in. long. Specimens of both types were 2½ in. thick.

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[1] University of Minnesota *Paper No. 1713*, Scientific Journal Series.

[2] Senior Drainage Engineer, Bureau of Agricultural Engineering, U.S. Department of Agriculture, University of Minnesota, University Farm, St. Paul, Minn.

[3] Assistant Biochemist, Division of Biochemistry, Agricultural Experiment Station, University of Minnesota, St. Paul, Minn.

[4] Instructor, Division of Agricultural Engineering, Agricultural Experiment Station, University of Minnesota, and Assistant Engineer, Minnesota State Department of Conservation, St. Paul, Minn.

A 1:3 mix of standard Ottawa sand mortar was used for the bars but with only 75 per cent of the quantity of water required for normal consistency, in order to have a consistency about that commonly used in the manufacture of dry-tamped staves. These bars had an average modulus of rupture of 450 psi., tested on a 12-in. span with load applied at the mid-point. The aggregate grading used in the manufacture of high-quality dry-tamped silo staves is about 75 per cent well-graded sand passing the No. 4 sieve and 25 per cent buckshot gravel retained on the No. 4 sieve. This was the aggregate grading used in the staves of these tests.

The solutions were applied to the specimens at the upper ends of the channels by a drip method using glass capillary tubes calibrated to deliver 2 liters of solution each 24 hr. A convenient head for the setup was about 13 in., and by experiment it was found that 1-in. lengths of capillary tubing with an opening of 0.009 in. closely delivered the desired quantity. Only minor adjustments of head were necessary to maintain a dropping rate of 10 per 37 sec. as was required to deliver 2-liter flow in 24 hr. Adjustments of head within the necessary limits were made by either raising or lowering the tip or the glass standpipe (see Figs. 1 and 2).

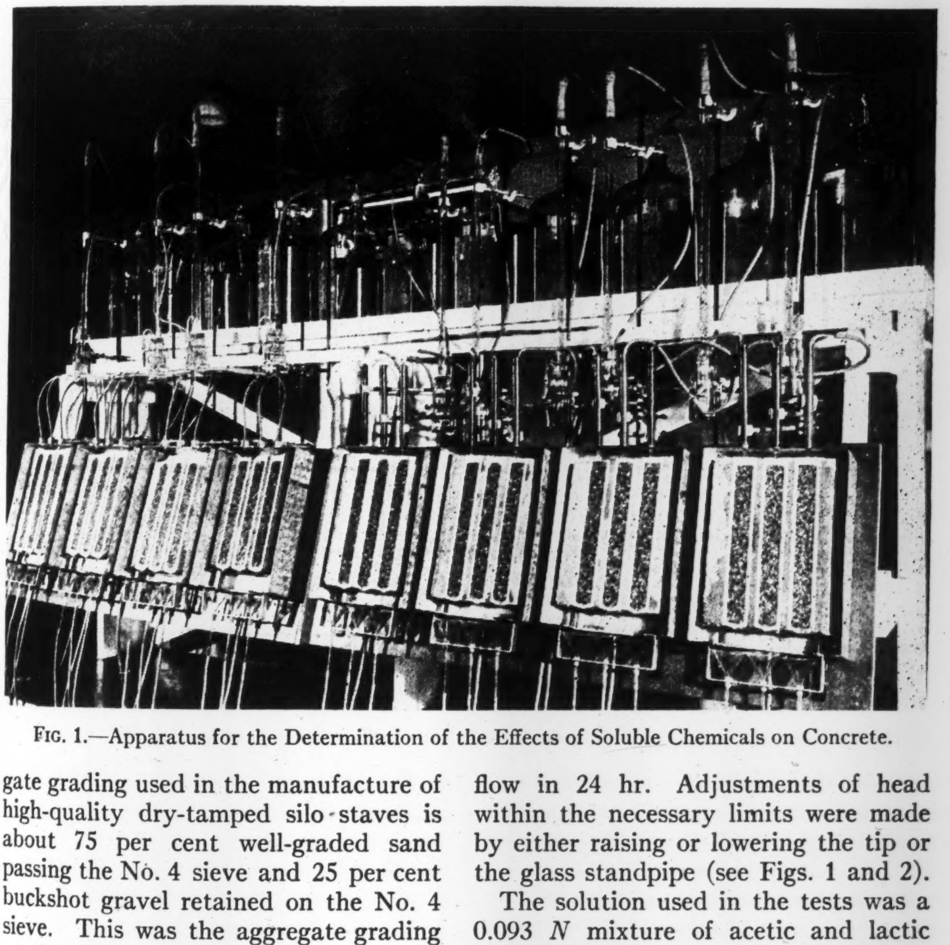

FIG. 1.—Apparatus for the Determination of the Effects of Soluble Chemicals on Concrete.

The solution used in the tests was a 0.093 *N* mixture of acetic and lactic acids consisting of 291 ml. of commercial acetic acid (56 per cent) and 240 ml. of clear U.S.P. lactic acid ("85 per cent," which actually was 73 per cent) to 54 liters of distilled water. The acidity of this mixture was pH 2.5 at room temperature. Used singly, the above quantities would be doubled for each acid and the acidity of the solutions would be at pH 2.9 and pH 2.3 for acetic and lactic, respectively.

In order to suppress fungus growth and prevent clogging of the capillaries, 1 g. of mercuric chloride ($HgCl_2$) was added to each 20 liters of the lactic acid solutions. Growth was slow in the clear lactic acid, and the addition of mercuric chloride was not necessary except for the longer runs. Any growth in the acetic acid was negligible.

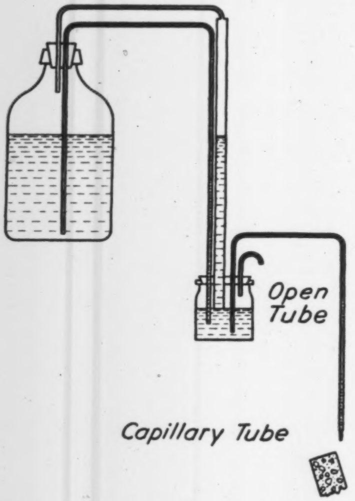

FIG. 2.—Side Elevation Showing the Essentials of a Single Unit for Controlling the Rate of Flow.

Every 24 hr. each channel was cleaned of loosened material by brushing 78 down strokes with a 1-in. flat brush of steel wire, the loosened material being caught in filter-paper-lined 6-in. funnels, oven-dried, and weighed. When brushing a channel, a small stream of water was applied to the top of it to wash the loosened material into the catching funnel. Brushing any channel more than 78 strokes did not appreciably increase the quantity of loosened material, and for all practical purposes 30 brush strokes would have been as satisfactory. In fact, well-made staves released little material after 15 strokes of the brush.

The apparatus devised for this test is relatively simple and the routine is not particularly exacting. It is believed the data of Tables I and II show a highly satisfactory uniformity of test results as indicated by the quantity of material loosened by each brushing.

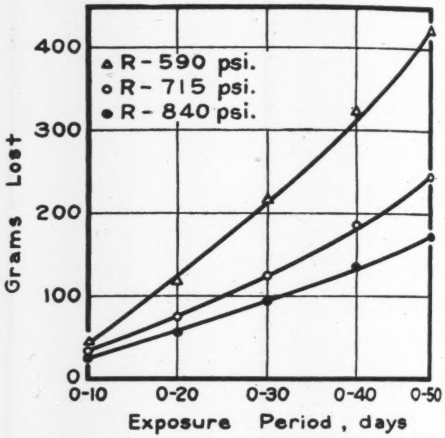

FIG. 3.—Material Lost from Three Concrete Staves of Different Strengths.

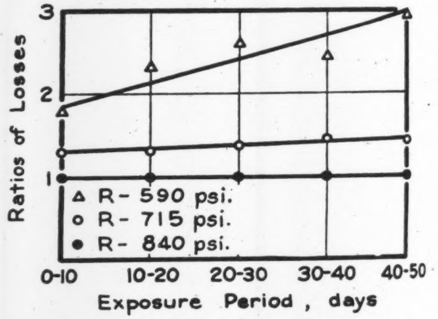

FIG. 4.—Ratios of Losses of Material from the Three Staves of Fig. 3.

The off-flow of solution from each channel was weighed every 24 hr. Because the specimens were kept in glass-covered metal pans at all times

TABLE I.—TWENTY-DAY RECORD OF BRUSHINGS FROM TEN SILO STAVES MADE AT A COMMERCIAL PLANT.

Note the consistent daily losses for individual specimens.

Duration of Exposure, days	Material lost from concrete staves, g.									
Flexural strength, lb. per inch of width	213	142	144	133	134	129	132	96	90	92
Modulus of rupture, psi	1227	818	829	766	772	743	760	553	518	530
1	0.9	2.2	2.2	3.8	4.2	3.8	4.9	4.1	6.5	7.1
2	2.1	2.8	3.1	3.3	2.8	3.5	2.8	4.8	4.6	4.9
3	2.4	2.8	2.8	3.2	2.7	3.5	3.2	4.5	4.6	4.3
4	2.8	3.0	3.4	3.1	3.1	3.5	3.9	5.3	4.1	5.4
5	2.2	2.4	2.9	2.4	1.0	2.6	3.5	4.2	4.6	5.0
6	2.8	2.3	2.5	2.8	2.4	2.8	3.5	5.0	5.8	5.9
7	2.5	2.0	1.9	2.4	2.1	2.7	2.9	4.5	5.1	5.9
8	2.1	2.2	2.5	2.2	2.7	2.2	2.9	5.3	5.4	7.4
9	2.7	2.4	3.4	2.9	2.7	2.4	3.2	6.7	6.6	7.1
10	2.1	2.1	2.1	2.6	2.4	3.1	2.5	4.9	6.6	5.9
11	2.4	2.1	2.4	2.4	3.6	3.4	3.0	5.7	6.3	6.5
12	1.9	2.1	2.6	2.3	2.2	2.4	2.4	5.7	7.4	7.5
13	1.8	1.5	2.3	1.8	3.6	2.3	3.1	5.1	3.9	7.8
14	2.2	2.0	2.9	2.1	3.9	3.6	2.8	8.2	7.3	7.8
15	2.3	1.7	2.6	2.6	3.6	2.9	3.5	5.0	5.7	10.0
16	1.8	2.2	2.2	2.4	1.1	2.4	3.1	5.6	7.4	7.7
17	2.5	2.4	2.9	3.4	2.6	4.5	3.2	8.1	7.9	6.6
18	1.5	1.7	3.0	3.0	2.9	3.0	2.5	6.7	7.9	4.6
19	2.3	2.1	1.8	2.4	4.5	4.1	3.8	6.3	5.7	8.0
20	1.8	1.6	2.5	2.1	3.6	3.0	3.9	6.5	7.0	9.6
Totals	43.1	43.6	52.0	53.2	57.7	61.7	64.6	112.2	120.4	135.0
Daily average	2.2	2.2	2.6	2.7	2.9	3.1	3.2	5.6	6.0	6.7
Loss ratios	1.00	1.01	1.21	1.23	1.34	1.43	1.50	2.60	2.79	3.13

TABLE II.—TWENTY-DAY RECORD OF BRUSHINGS FROM ELEVEN BARS OF STANDARD OTTAWA SAND MORTAR MADE OF DIFFERENT CEMENTS.

Note the consistent daily losses for individual specimens.

Duration of Exposure, days	Material Lost from Bars of Standard Ottawa Sand, g.										
	Cement No. 740	Cement No. 725	Cement No. 739	Cement No. 737[a]	Cement No. 736[b]	Cement No. 738[b]	Cement No. 732	Cement No. 735[a]	Cement No. 728	Cement No. 729	Cement No. 727
1	1.4	1.5	1.5	1.5	2.5	2.1	2.9	4.1	3.1	6.1	6.3
2	3.4	4.4	4.2	5.5	6.2	6.1	6.9	7.4	7.5	8.0	8.0
3	4.1	5.9	5.8	4.7	5.1	6.1	6.1	5.8	6.2	7.3	7.4
4	4.8	6.2	5.6	6.0	6.1	5.6	6.7	7.0	7.1	7.8	7.6
5	5.6	6.5	6.4	7.1	7.1	6.5	7.1	6.9	7.6	8.0	8.7
6	5.4	5.7	6.5	6.5	5.9	6.7	6.4	6.5	7.2	7.8	6.6
7	5.1	6.7	6.1	7.0	6.9	6.1	7.2	6.9	7.1	8.0	9.7
8	6.3	5.5	7.2	7.9	7.3	7.6	6.8	6.7	7.1	8.0	8.1
9	6.1	7.6	7.0	7.0	6.9	6.6	7.1	7.7	7.9	8.3	8.9
10	6.4	8.2	7.5	7.9	8.3	8.1	8.1	8.1	9.0	9.2	10.3
11	6.9	6.0	7.6	7.6	7.0	7.1	7.8	7.2	7.2	8.2	7.5
12	6.5	7.6	6.8	7.6	6.7	7.4	7.0	7.3	8.3	8.6	8.6
13	4.7	7.2	6.2	6.3	8.0	6.2	8.3	7.3	8.3	7.9	8.7
14	5.3	7.9	8.2	7.3	8.1	7.8	7.7	7.3	9.7	9.3	9.9
15	4.7	6.3	6.8	6.5	5.7	6.1	6.0	6.0	6.2	6.7	7.1
16	5.1	6.9	7.0	7.0	7.3	7.6	7.3	7.8	7.7	9.1	8.5
17	5.1	6.1	7.7	5.2	6.4	6.8	6.1	6.4	6.7	7.6	7.8
18	5.0	6.4	7.5	8.3	6.6	8.1	7.2	7.1	7.3	8.2	7.9
19	5.2	6.2	6.6	7.3	7.3	6.8	6.8	6.4	7.7	7.7	8.3
20	4.2	6.3	7.3	6.4	7.1	7.1	7.6	7.7	8.8	9.3	8.5
Totals	101.3	125.1	129.5	130.6	132.5	132.5	137.1	137.6	147.7	161.1	164.4
Daily average	5.1	6.3	6.5	6.5	6.6	6.6	6.9	6.9	7.4	8.1	8.2
Loss ratios	1.00	1.23	1.28	1.29	1.31	1.31	1.35	1.36	1.46	1.59	1.62

[a] Standard portland cement.
[b] High-early-strength cement.

during the tests except when being brushed, evaporation losses were small. Only a few lean-mixed staves permitted the solutions to pass through them, so the quantity of off-flow from the channel in general closely checked with the onflow. About 10 per cent of the applied solution passed through the most permeable stave, while some solution passed through other low-grade staves. Provisions were made for collecting this in separate containers. Many pH determinations were made of the off-flow from all channels and of samples of the solutions collected at the quarter and mid-points of the specimens and of that which passed through the more permeable staves.

Results of Some of the Tests:

The graphs of Figs. 3 and 4 are plotted from data obtained by flowing for fifty days 0.093 *N* solutions of a mixture of acetic and lactic acids across the faces of halves of three $2\frac{1}{2}$ by 10 by 30-in. concrete silo staves. The flexural strengths at 28 days of these staves were 102, 124, and 146 lb. per inch of width (24-in. span and load applied at midpoint) and the moduli of rupture were 590, 715, and 840 psi., respectively. The three staves, which were made at the same plant, differed only in the richness of the mix, with a slightly higher water-cement ratio for the lean mix in order to maintain the required consistency. The water-cement ratio for dry-tamped staves of the richer mixes is ordinarily about $3\frac{1}{2}$ gal. per sack of cement. The stave with a modulus of rupture of 590 psi. was from a lot made 12 staves per sack of cement while the staves with moduli of rupture of 715 and 840 psi. were from lots made 9 and 7 staves, respectively, per sack of cement. The accumulated losses of material at 10-day intervals are shown in Fig. 3 while loss ratios for each 10-day period are shown for the three staves in Fig. 4.

The graphs of Fig. 5 show the relative resistance to a 0.093 *N* mixture of acetic and lactic acids of 26 silo staves as indicated by the quantity of material loosened after 30 daily brushings. Eleven staves were made at plant A, thirteen at plant B, and two at plant C. The plant A and plant B curves are similar. The losses were greater for the staves from plants B and C than for those from plant A when considered on a strength basis. The behavior of the staves from plant C is readily explained because the aggregate used at that plant carried $3\frac{1}{2}$ per cent shale while that used at the other two plants carried less than $\frac{1}{2}$ per cent. The differences in losses displayed by the staves from plants A and B are not so readily explained and are not considered in this paper which deals with a test method rather than with test results. It is obvious that the lower ends of the graphs of Fig. 5 are constructed from meager data because few points were available for staves with a modulus of rupture in excess of 850 psi. It is evident, however, that the break in the direction of the curves must come some-

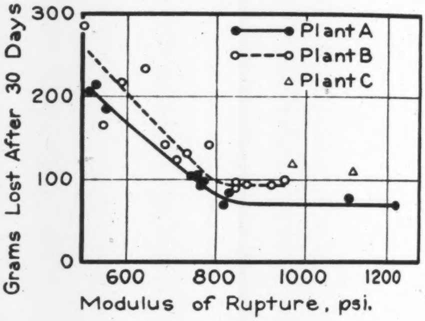

FIG. 5.—Material Lost from 26 Concrete Staves of Widely Different Strengths.

Note that losses of material did not increase for moduli of rupture above 850 psi.

where below a modulus of rupture of 1000 psi.; therefore these graphs as drawn cannot be much in error.

min., following oven-drying at 240 F., progressively decreased as the flexural strengths increased to 140 lb. per inch

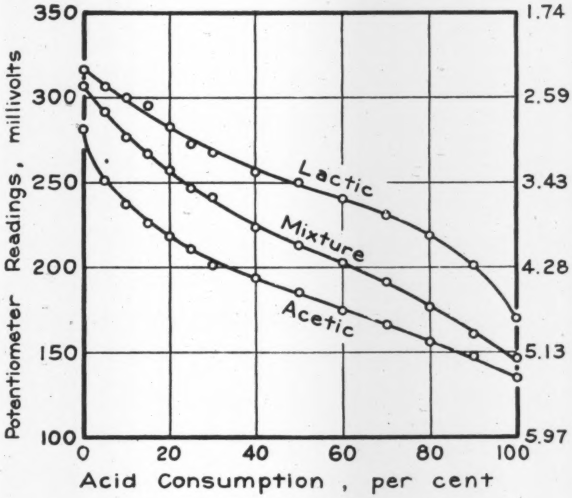

FIG. 6.—Experimental Curves Showing Relation Between the Consumption of Acid as Used in the Tests and Potentiometer Readings.

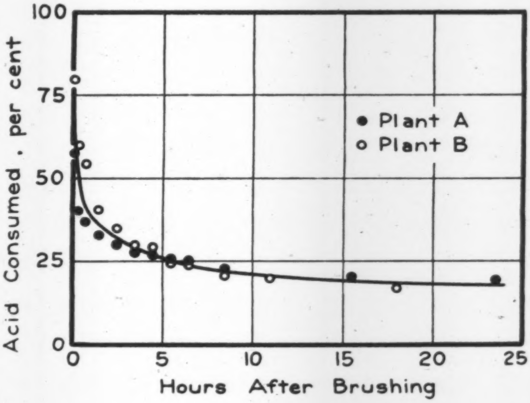

FIG. 7.—Effect of Brushing on Acid Consumption.
Each point is the average for four staves.

It has been found[5] that the regain of water by dry tamped concrete silo staves of this type after soaking for 10 of width, while the gain was about constant between 1 and 2 per cent for staves testing stronger than 140 lb. This flexural strength represents a modulus of rupture of about 800 psi. and apparently marks a critical change in density of the staves. It so happens that in the plant processes ordinarily used in making concrete silo staves it is difficult to manufacture staves with a modulus of rupture of 800 psi. except by the use of rich mixes with a cement-void ratio approaching 1.00. In the tests as conducted, when this ratio decreased, the resistance of the staves to the acids became less. Tests have been made on only a few staves with a cement-void ratio in excess of 1.00, but such as have been made do not indicate greatly increased resistance to acid corrosions. Keeping in mind that some loss must always follow exposure of concrete to acid under the routine of the test herein described, a study of Fig. 5 will show that the possibilities of greatly reducing the losses from the more resistant type of specimen used appear to be extremely remote unless by some means the density of the product can be appreciably increased or unless the cement itself can be made more resistant.

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[5] Dalton G. Miller, "Factors Which Influence the Durability of Concrete Stave Silos," *Journal*, Am. Concrete Inst., March–April, 1938, p. 395.

Acid Consumption:

The degree of acidity was determined for many samples of the solutions flowing over the surfaces of the specimens in order to study the possible correlation of the quantity of acid consumed with known characteristics of the concrete or mortar. To facilitate this phase of the studies, the experimental curves of Fig. 6 were constructed. As only four drops of a solution were required for a potentiometer reading, the whole operation of collecting a sample, reading, and recording the resistance was a matter of only a few minutes. Figure 7 shows the average percentage of acid consumed at various time intervals as determined for off-flow samples of a 0.093 N solution of acetic and lactic acids from eight silo staves. Each point is the average of 4 staves from one of two plants. The moduli of rupture of the staves ranged between 530 and 840 psi. for flexural strengths between 92 and 146 lb. The acid consumption dropped rapidly from 70 per cent for the first 15 min. to about 25 per cent at 5 hr., and thereafter the change of rate was slow.

Reduction in rate of use was probably the result of accumulation of inert residue from the chemical action of these acids on the constituents of the cements. This layer was removed when the channel was brushed, and the rate of chemical action increased for a time. The amount of acid consumed during the first 12-hr. period was slightly in excess of 60 per cent of the total for 24 hr., indicating that brushing twice daily instead of once would increase the quantity of loosened material something like 20 per cent. Brushing at hourly intervals might increase the loosened material as much as 100 per cent per day.

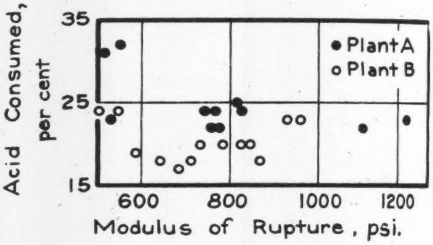

FIG. 8.—Relation Between Acid Consumption and the Strength of Concrete Staves.

It is not apparent that there is any correlation unless it is indicated for the weaker concrete.

From a study of Fig. 8, it appears that consumption of acid has no particular relation to the quality of the concrete unless greater acid consumption is indicated in extremely low-grade concrete. As this test was applied, it would seem that the constituents of the cement available for the acid requirements were about equal in all the specimens, although a greater quantity of aggregate was loosened by deeper penetration of acid into the more permeable lean-mixed staves than was loosened in the rich-mixed and dense staves as shown in Figs. 3, 4, and 5.

The weaker specimens yielded about three times as much material as did the stronger ones. Stating it in another way, the depth of corrosion in the weaker specimens was about three times that of the stronger ones. A practical inference of this fact is that the low-quality specimens could not last more than one-third as long as those of high quality under conditions of exposure represented by these tests.

Resistance of Cements to Acid:

Nine standard portland cements and two high-early-strength cements were subjected to the flow test for resistance to a 0.093 *N* solution of acetic and lactic acids by use of the specially made 2½ by 3 by 15-in. bars. The order of listing of the cements in Table II is the same as the loss ratios after exposure for twenty days, taking as unity the quantity lost from the most resistant of the eleven specimens. The greatest difference in resistance of the nine standard portland cements was as 1.0 is to 1.6. This difference is small compared to that of 1 to 10 which has been found in connection with specimens exposed to solutions of sodium and magnesium sulfate,[6] but is still large enough to be significant.

Chemical analyses of these cements are not included in this paper because it is felt that no useful purpose would be served by any conclusions based on these limited tests. It may be of interest, however, to mention that the standard portland cements that made the best showing of resistance to acids generally were ones which have been found to be resistant to sulfates. The two high-early-strength cements included in the group gave results almost identical with those of their companion standard portlands. In Table II the standard portlands are numbered 735 and 737, while the companion high-early-strength cements are numbered 736 and 738, respectively.

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[6] Dalton G. Miller and Philip W. Manson, "Laboratory and Field Tests of Concrete Exposed to the Action of Sulphate Waters," *Technical Bulletin No. 358*, U.S. Department of Agriculture, p. 44.

DISCUSSION

Mr. Joshua L. Miner.[1]—This test described in the paper is very interesting for several reasons. It is similar to a test method used for several years by Rengade of the LaFarge Cement Co. However, I believe that the authors' procedure is an improvement. Whereas Rengade's results were largely qualitative, the author's method permits quantitative measurements. Another interesting feature of the test is that it can be used for testing field-made as well as laboratory-made specimens. Also it can be used with natural solutions as well as synthetic laboratory solutions.

The authors' results emphasize the value of density. We all will agree with them that density is a fundamental requirement in the durability of any concrete.

In connection with the use of solutions, I want to warn against the all too common practice of using laboratory solutions in an attempt to predict what will happen in the field. Laboratory solutions are never the same as those encountered in the field. The chemical reactions that take place with the natural solutions differed from those that take place when straight acids or synthetic laboratory solutions are employed.

Mr. J. T. MacKenzie.[2]—Regarding a point of testing procedure, I would like to ask whether the authors determined how much the brush would take off of those different concretes without the acid, or, as a further check, using plain water. It seems to me you would get some loss that way.

Mr. Dalton G. Miller.[3]—We did run distilled water over a few specimens and the amount of material released within a period of satisfactory test, say 20 days, was insignificant. In either of the tables there was scarcely any day but what there was released in the neighborhood of 2 g. of material, or considerably more, depending on the type of the specimen. Running distilled water over a low quality stave of high permeability rarely ever released even as much as 0.1 g., an amount so insignificant that we dismissed it from consideration.

Mr. J. C. Witt.[4]—I should like to ask whether the dissolved material was determined.

Mr. Miller.—The amount of acid consumed by any given channel, regardless of the type of specimen, was about constant. Now that rather surprised us because, in advance, you might assume that the constituents of the cement would consume the most acid on those specimens from which the most material was released. The fact that the difference in the acid consumption of these channels was surprisingly constant indicates that, for the more permeable specimens which, as it happened in these tests, were the leaner mixed ones, the acid had to go to a greater depth in order to satisfy its requirements during the short time in contact, and this was about to the same degree for any cement or any specimen tested. This is about the only attempt we have made regarding the constituents removed by the acid flow. Does this answer your question?

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[1] Vice-President, Atlas Lumnite Cement Co., New York City.

[2] Chief Chemist, American Cast Iron Pipe Co., Birmingham, Ala.

[3] Senior Drainage Engineer, Bureau of Agricultural Engineering, U. S. Department of Agriculture, University of Minnesota, University Farm, St. Paul, Minn.

[4] Technical Service Manager, Marquette Cement Manufacturing Co., Chicago, Ill.

MR. WITT.—Yes, that answers my question, thank you. The material dissolved should have a more or less definite relation to the insoluble material, but the analysis of the former would be of interest.

MR. C. A. HUGHES[5] (*by letter*).—For the past 2 yr. the writer has been making acid tests of mortars for purposes similar to those motivating the authors, but has used a different procedure. The results of his tests are in agreement with those of the authors in that they indicate that stronger concretes are more resistant to acid, and that resistance to acid is affected by the cement. As for freezing-and-thawing tests, the chief problem in acid tests will lie in the interpretation of the data in terms of years of service or in terms of relative life under service conditions.

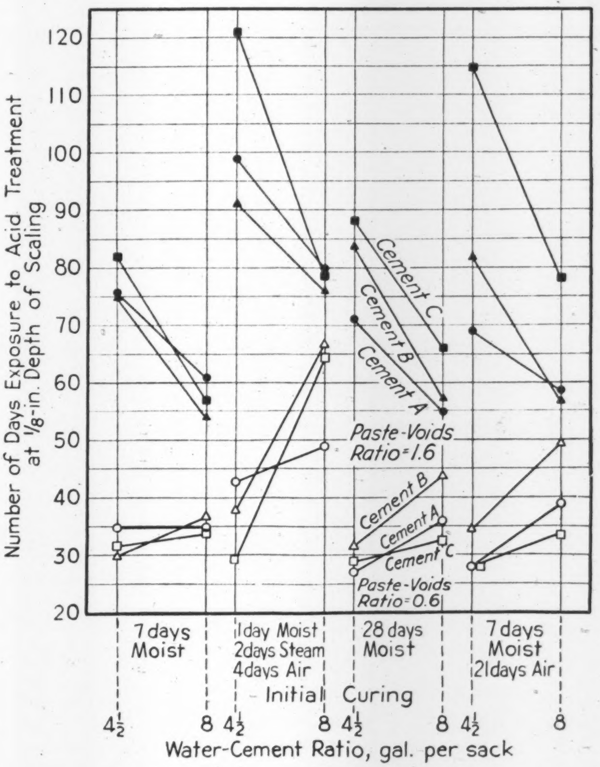

FIG. 1.—Results of Tests on 2-in. Cubes.

In the writer's tests, mortar cubes, either cast or cut from silo staves, are used as specimens. These are submerged in the acid solution for one day and stored in air for one day, and this cycle is repeated until the conclusion of the test. The acid solution is similar to that used by the authors except that the nominal normality is 0.16 instead of

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[5] Associate Professor of Structural Engineering, University of Minnesota, Minneapolis, Minn.

0.093. When submerged, the specimens are supported on a copper wire rack so placed that the tops of the specimens are about 1½ in. below the surface of 12 liters of solution contained in 5-gal. crocks. Once a week the specimens are blown off with a standardized air stream and weighed. At the same time, the acid solution is replaced. The use of an air stream has been found in these tests, as in freezing-and-thawing tests, to be a very satisfactory method for removing loosened material and for surface drying.

When submerged in acid solutions, mortar specimens change in volume but not in shape. Except for projecting aggregate particles, the corners of cubes are closely as square and the faces closely as plane at the end of the test as at the start. This behavior of acid specimens permits the use of the depth of scaling as a measure of the effect of the acid. The criterion of resistance to acid action is, then, the number of days treatment required to cause a given depth of scaling.

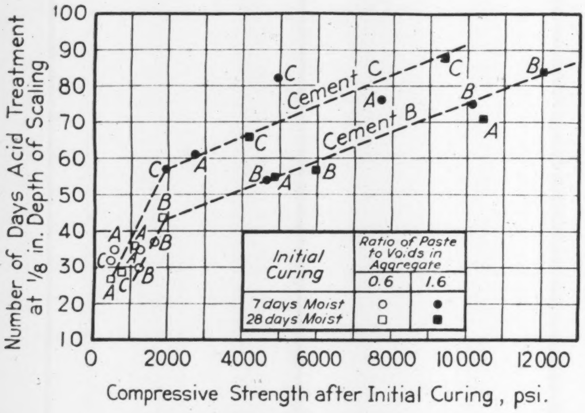

FIG. 2.—Results of Tests on 2-in. Cubes.

The depth of scaling is a particularly useful criterion in that it is usually used in field surveys. The ⅛-in. depth of scaling used by the writer as an end point corresponds to 33 per cent loss in weight for a 2-in. cube.

The accompanying Figs. 1 and 2 show a few data obtained from a series of tests on 2-in. cubes made by T. R. Klingel, a graduate student working under the writer's direction. Each point on both figures represents the average for two specimens. Cement A was a standard portland cement and cement B a high-early-strength portland cement made by the same company. Cement C was a low-heat cement selected for these tests because it was high in iron. Half the specimens were made with a ratio of the volume of paste (cement plus water) to the volume of voids in the aggregate of 1.6 and half with this ratio 0.6. Those with a ratio of 1.6 were plastic and were cast in molds in the usual manner. Those with a ratio of 0.6 were nonplastic and were dry-tamped in a small stripper machine designed for this purpose. With two water-cement ratios, there were four mixes for each cement. Four initial curings, as indicated on Fig. 1, were used, after which the specimens were subjected to acid treatment until the depth of scaling was slightly in excess of ⅛ in. They were then washed with water, capped, and tested in compression. Companion specimens stored in the moist room during the period of the acid tests were tested at the same time. Data for the compression tests are given in the accompanying Table I.

Figure 1 clearly indicates that, when compared on a basis of similar proportions, some variation in acid resistance results from the use of different cements, and that the degree of variation is affected by the initial curing. Using the averages for the four mixes, the ratios of the resistance to acid action for cements A, B and C are 1.0, 0.94, and 1.0 for 7 days initial moist curing, and 1.0, 1.15, and 1.17 for 28 days initial moist curing. Excepting the extreme cements, Nos. 740, 729, and 727 from Table II of the authors' paper, the ratios of the weights removed by brushing are 1.0, 1.04, 1.05, 1.08, 1.06, 1.10, and 1.185. The greatest difference caused by the cement in the writer's tests was for the plastic mixes made with 4$\frac{1}{2}$ gal. per sack, and cured initially 7 days moist and 21 days in air. For this set the ratios for cements A, B, and C are 1.0, 1.19 and 1.67, respectively.

TABLE I.—RATIOS OF COMPRESSIVE STRENGTHS OF CUBES AFTER ACID TREATMENT TO THE COMPRESSIVE STRENGTHS OF CUBES OF THE SAME AGE, BUT MOIST-CURED FOLLOWING INITIAL CURING.

Cement	Water-Cement Ratio, gal. per sack	Paste-Voids Ratio	Initial Curing			
			7 days Moist	28 days Moist	7 days Moist, 21 days in Air	1 day Moist, 2 days in Steam, 4 days in Air
A	4½	0.6	1.07	0.80	0.91	0.98
	4½	1.6	0.42	0.46	0.49	0.47
	8	0.6	0.74	0.89	0.93	1.10
	8	1.6	0.49	0.43	0.52	0.78

In Fig. 2, the number of days acid treatment for $\frac{1}{8}$-in. depth of scaling are plotted against the compressive strengths at the beginning of acid treatment. As in the authors' tests, the stronger specimens are the more resistant. While the data are few and somewhat scattered, they appear to indicate the trends shown by the dashed lines for cement C and B.

In another series of tests, the data on specimens cut from 71 staves involving a large number of variables in proportions, materials, and plant show an extreme range in resistance of from 36 to 63 days acid treatment, a ratio of 1 to 1.75 for specimens Nos. 24 and 30, respectively. The moduli of rupture for the staves from which these specimens were cut were 476 and 1050 psi., respectively. These strengths correspond roughly to those for specimens having flexural strengths of 213 and 92 in Table I of the paper, for which the loss ratios are 1 to 3.13 at 20 days. Hence, while the two methods of test agree qualitatively, there is considerable quantitative difference, which will become important only if these ratios are interpreted as indicating relative life in service.

The quantitative difference in the two methods is believed to be due chiefly to difference in the penetration of the acid solution. It is stated by the authors that about 10 per cent of the solution passed through the most permeable stave. Presumably this fraction of the solution would be completely neutralized, whereas the run-off acid is shown by Fig. 7 of the paper to be less than 25 per cent neutralized after the first 5 hr. With 10 per cent of the solution completely neutralized, and 90 per cent one-quarter neutralized, the acid consumed is 32.5 per cent. This is an increase of 30 per cent. The progressive loosening of aggregate particles, due to the percolating solution, would account for the increasing ratio of loss with time of exposure shown by Fig. 4 of the paper for the specimen having R = 590 psi. Permeability tests made by the writer indicate the probability that the 590-psi. specimen would be permeable under low heads, whereas there would be no outflow from the 715 and 840-psi. specimens. The acid action for the latter specimens would occur on the surface only, and therefore the ratios of loss should be constant throughout the test. Since the permeability of specimen No. 24 of the writer's tests was 45 cu. ft. per hr. per sq. ft. at 15 min. under a 15-ft. head of water, and specimen No. 30 had zero outflow under the same conditions, there is little doubt that the ratio of 1.75 would have been increased using the authors' method. The above argument suggests that a change in slope of the specimens when under test would modify the authors' ratios for permeable staves.

The protection afforded the underlying concrete by the corroded surface layer, shown very nicely by Fig. 7 and discussed by the authors, has also been noted by the writer. Cubes blown off every three weeks showed a depth of scaling 81 per cent of that of cubes blown off every week.

The data of Table I were contrary to the expectations of the writer. Though difficult to explain, they do indicate that the strength of the residual concrete is an additional factor that should be considered when attempting to evaluate acid resistance.

MR. MILLER.—It has been a pleasure to review the discussion by Mr. Hughes and to note that in general there appears to be reasonable correlation between results obtained by the two test methods in so far as the bases for comparison are at all common.

Mr. Hughes comments on the discrepancy of results indicated by his Fig. 1 and the test data of Table I of the paper. Referring to his Fig. 2, it is noted that the compressive strengths of the non-plastic mixes used in these tests are extremely low, ranging between 500 and 2000 psi., whereas the strengths of the plastic mixes ranged upward from 2000 to 12,000 psi. The thought occurs that the air stream may have produced a mild sand blast effect which mechanically removed material from the specimens of extremely low unit strengths slightly faster than it was fully released by the acid action, while the same air stream applied to the specimens of relative high unit strengths may have had less relative mechanical effect.

THE EFFECT OF BIOT'S MODULUS ON TRANSIENT THERMAL STRESSES IN CONCRETE CYLINDERS

By Gerald Pickett[1]

Synopsis

The durability of concrete is determined by freezing-and-thawing, heating-and-cooling, and wetting-and-drying tests. This paper investigates one type of thermal stress produced in such tests. Theory of heat flow is combined with experimental data to determine an equivalent Biot's modulus, a non-dimensional parameter giving the thermal boundary conditions. A solution for the theoretical transient thermal stresses as functions of this modulus is given. It is found that these stresses vary widely with these test methods, being large enough in some cases to be a cause of concrete failure while negligible in other cases. It is believed that information as to the magnitude of thermal stresses in durability tests is important, and that sufficient theory has been developed to determine these stresses.

This paper is concerned with the transient thermal stresses produced in concrete cylinders when subjected to laboratory durability tests, which tests involve temperature change. If the temperature range is from below to above the freezing point of water, the test is described as a freezing-and-thawing test; if the temperature range is above the freezing of water it is called a heating-and-cooling test. Some tests in the latter temperature range are sometimes called wetting-and-drying tests. The name of the test indicates, to some extent, the commonly accepted reason as to why some concrete deteriorates in the test; that is, in the freezing-and-thawing test it is believed that the expansion of water freezing internally is the main factor causing breakdown. In the heating-and-cooling test the specimens are usually kept submerged in water and any deterioration should be due to temperature change. In the wetting-and-drying test it is thought that the change of moisture content may be the controlling factor causing deterioration. In general, thermal stresses are of two kinds: first, those due to variable values of the coefficient of expansion; second, those due to temperature differences throughout the body. This paper deals only with the second kind of test, and only for cylinders. In more technical words, the thermal stresses to be considered are those produced in a homogeneous, isotropic cylinder due to temperature change. It is assumed that the elastic and thermal "constants" are also independent of temperature. Theoretical analysis shows that the stresses will vary with time and boundary conditions as well as throughout the body. The magnitude of maximum stress during a cycle of temperature change depends on the shape of the body, the elastic constants, and Biot's modulus. So far as is known, the mathematical derivation of stresses as functions of the latter factor have not previously been made. In all problems of mathematical physics, a most important consideration is the boundary condition. Biot's modulus is a non-dimensional quantity giving considerable information about the boundary condition.

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[1] Associate Professor of Applied Mechanics, Kansas State College, Manhattan, Kans.

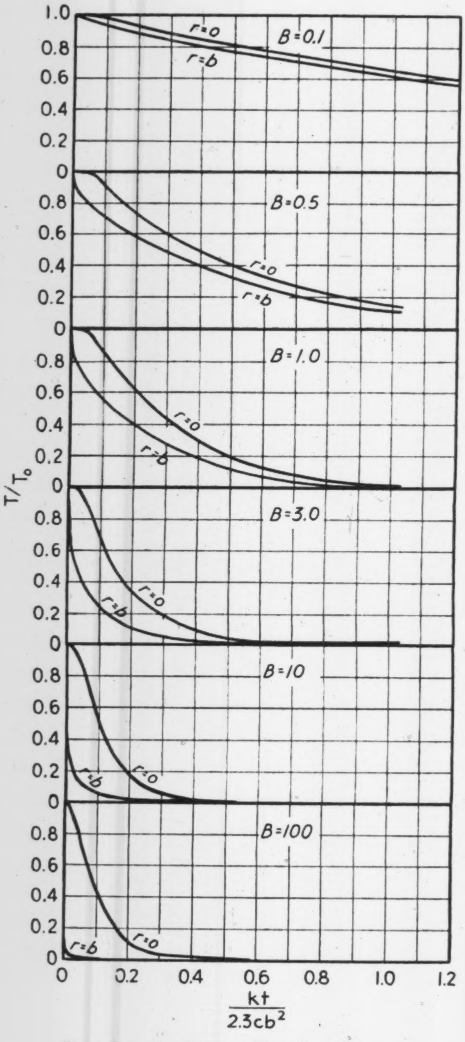

FIG. 1.—Cooling or Heating Curves.

Temperature *versus* time of center and surface of cylinder.

It is assumed that all covering or insulation, such as the rubber sack sometimes used to keep specimens dry, surface films of air or liquid, etc., may all be considered equivalent to one film of conductivity k' thickness b', and negligible specific heat. Biot's modulus is then defined by the equation

$$B = \frac{k'b}{kb'}$$

where k = the thermal conductivity, and

b = the radius of the cylinder.

For a perfect insulator $B = 0$, and the other extreme usually assumed in elementary Fourier heat-conduction problems is that $B = \infty$. The exact value of B for a given test may not be known, but an equivalent B may be estimated by comparing experimental temperature curves with theoretical ones. The method is explained later.

The mathematical derivation of stresses follows:

Notation:

r, Θ, z = cylindrical coordinates,
b = radius of cylinder,
b' = equivalent thickness of covering,
l = length of cylinder,
α = linear coefficient of thermal expansion,
k = thermal conductivity,
k' = equivalent thermal conductivity of covering,
c = specific heat per unit volume,
T = temperature difference between an interior point and external medium,
T_0 = initial temperature difference assumed uniform in specimen,
t = time,
$B = \frac{k'b}{kb'}$, Biot's modulus,

$F = \frac{k}{c}\frac{t}{b^2}$, Fourier's modulus,
$J_n(x)$ = Bessel's function of order n,
β_n = a root of the trancendental equation $\beta J_1(\beta) = BJ_0(\beta)$,
A_n = Fourier coefficient of Bessel's function,
Δ = Laplace operator,
E = Young's modulus of elasticity,
μ = Poisson's ratio,
S_r, S_θ, S_z = radial, tangential, and axial normal stresses, and
r = a coordinate, and
dr = a differential.

When the conductivity and specific heat are independent of the temperature, the equation of heat flow becomes:[2]

$$c\frac{\partial T}{\partial t} = k\Delta T \quad \ldots\ldots\ldots\ldots (1)$$

The general solution[3] of Eq. 1 for a cylinder of infinite length is:

$$T = \sum_{n=1}^{\infty} A_n e^{-F\beta_n^2} J_0\left(\beta_n \frac{r}{b}\right) \quad \ldots\ldots (2)$$

The β's are chosen to satisfy the boundary conditions at $r = b$, and the A's are chosen to satisfy the conditions at $t = 0$.

Equating the rate of heat flow per unit area through the protective covering or surface film to the rate of heat flow per unit area through the surface of the cylinder we have at $r = b$:

$$\frac{k'T}{b'} = -k\frac{\partial T}{\partial r} \quad \ldots\ldots\ldots\ldots (3)$$

Substituting Eq. 2 in Eq. 3 and using the fact that Eq. 3 is true, independent of t, we have:

$$\frac{k'J_0(\beta_n)}{b} = \frac{k\beta_n}{b} J_1(\beta_n), \quad \text{or}$$

$$\beta_n J_1(\beta_n) = BJ_0(\beta_n) \quad \ldots\ldots\ldots\ldots (4)$$

Equation 4 shows that the β's depend only upon Biot's modulus B. As a special case, when $B = \infty$, Eq. 4 becomes $J_0(\beta_n) = 0$, and these β's may be found in any standard text on Bessel's functions.

The A's are found in the regular way of obtaining Fourier coefficients by making use of the orthogonality of Bessel's functions. For the special case of uniform temperature T_0 when $t = 0$, it can be shown that:[4]

$$A_n = \frac{2BT_0}{(B^2 + \beta_n^2)J_0(\beta_n)} \quad \ldots\ldots\ldots (5)$$

If we assume, as above, a cylinder of infinite length, the stresses are as follows:[5]

$$\left.\begin{aligned}
S_r &= \frac{E\alpha}{1-\mu}\left[\frac{1}{b^2}\int_0^b Trdr - \frac{1}{r^2}\int_0^r Trdr\right] \\
S_\theta &= \frac{E\alpha}{1-\mu}\left[\frac{1}{b^2}\int_0^b Trdr + \frac{1}{r^2}\int_0^r Trdr - T\right] \\
S_z &= E e_z + \frac{E\alpha}{1-\mu}\left[\frac{2\mu}{b^2}\int_0^b Trdr - T\right]
\end{aligned}\right\}(6)$$

Substituting Eq. 2 in Eq. 6, and using the fact that

$$\int_0^r J_0\left(\beta_n \frac{r}{b}\right) rdr = \frac{br}{\beta_n} J_1\left(\beta_n \frac{r}{b}\right)$$

We obtain

$$\left.\begin{aligned}
S_r &= \frac{E\alpha}{1-\mu}\sum_{n=1}^{\infty}\frac{A_n e^{-F\beta_n^2}}{\beta_n} \\
&\qquad \left[J_1(\beta_n) - \frac{b}{r}J_1\left(\beta_n\frac{r}{b}\right)\right] \\
S_\theta &= \frac{E\alpha}{1-\mu}\sum_{n=1}^{\infty}\frac{A_n e^{-F\beta_n^2}}{\beta_n} \\
&\qquad \left[J_1(\beta_n) + \frac{b}{r}J_1\left(\beta_n\frac{r}{b}\right) - \beta_n J_0\left(\beta_n\frac{r}{b}\right)\right] \\
S_z &= E\epsilon_z + \frac{E\alpha}{1-\mu}\sum_{n=1}^{\infty}\frac{A_n e^{-F\beta_n^2}}{\beta_n} \\
&\qquad \left[2\mu J_1(\beta_n) - \beta_n J_0\left(\beta_n\frac{r}{b}\right)\right]
\end{aligned}\right\}(7)$$

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[2] W. F. Osgood, "Advanced Calculus," p. 247, Macmillan Co., New York City (1929).

[3] W. E. Byerly, "Fourier Series and Spherical Harmonics," p. 15, Ginn and Co., Boston (1895).

[4] W. E. Byerly, "Fourier Series and Spherical Harmonics," p. 229, Ginn and Co., Boston (1895).

[5] S. Timoshenko, "Theory of Elasticity," p. 368, McGraw-Hill Book Co., Inc., New York City (1934).

Solving for ϵ_z so as to make $2\pi \int_0^b S_z r dr = 0$ we find

$$\epsilon_z = 2\alpha \sum_{n=1}^{\infty} \frac{A_n e^{-F\beta_n^2}}{\beta_n} J_1(\beta_n) \ldots\ldots (8)$$

Substituting Eqs. 4, 5, and 8 in Eqs. 7 we find

$$\left.\begin{aligned}
S_r &= \frac{2E\alpha T_0}{1-\mu} \sum_{n=1}^{\infty} e^{-F\beta_n^2} \frac{B}{(B^2+\beta_n^2)} \\
&\qquad \left[\frac{B}{\beta_n^2} - \frac{b}{r}\frac{J_1\left(\beta_n \frac{r}{b}\right)}{\beta_n J_0(\beta_n)}\right] \\
S_\theta &= \frac{2E\alpha T_0}{1-\mu} \sum_{n=1}^{\infty} e^{-F\beta_n^2} \frac{B}{(B^2+\beta_n^2)} \\
&\qquad \left[\frac{B}{\beta_n^2} + \frac{b}{r}\frac{J_1\left(\beta_n \frac{r}{b}\right)}{\beta_n J_0(\beta_n)} - \frac{J_0\left(\beta_n \frac{r}{b}\right)}{J_0(\beta_n)}\right] \\
S_z &= S_r + S_\theta = \frac{2E\alpha T_0}{1-\mu} \sum_{n=1}^{\infty} e^{-F\beta_n^2} \\
&\qquad \frac{B}{(B^2+\beta_n^2)}\left[\frac{2B}{\beta_n^2} - \frac{J_0\left(\beta_n \frac{r}{b}\right)}{J_0(\beta_n)}\right]
\end{aligned}\right\} (9)$$

RESULTS

Equations 9 are the mathematically exact equations for stress at any point, at any time, for any Biot's modulus. The actual stresses will differ from the above chiefly because of variation of the thermal and elastic coefficients.

It is not easy to find the value of the stresses from the above equation. One could proceed as follows: first, from test conditions a value of B is selected, then a sufficient number of β's are evaluated as roots of Eq. 4. In most cases, four or five β's are enough for good accuracy, but in some cases many more are required. Finally, the desired F and r are chosen, and substitution may be made in Eqs. 9.

Since the equations are not in a form that can be readily used, curves have been prepared. Figure 1 shows cooling curves for the surface and for the center of a cylinder for various values of Biot's modulus. A comparison of actual curves, obtained with thermocouples, and these theoretical curves enables one, in most cases, to decide as to the approximate value of Biot's modulus for the particular test. For example, B was found to be between 5 and 10 for a 3 by 6-in. cylinder warmed or cooled by sudden immersion in a tank of still water. B was found to be between 0.3 and 0.5 for the same cylinder warmed or cooled in still air. These values would be raised, depending upon the relative intensity of the circulation of the water or air. When the cylinder is sealed inside an inner tube which is then submerged in liquid, B is approximately 3. It is evident from the above that the value of B varies widely with different methods of tests.

The first several roots of Eq. 4 for various values of B are shown below:

B	β_1	β_2	β_3	β_4	β_5	β_6
0.1	0.441680	3.858	7.030	10.171	13.326	16.47
0.5	0.940	3.959	7.0865	10.222	13.361	16.51
1	1.25579	4.0795	7.1555	10.269	13.399	16.54
3	1.7885	4.463	7.408	10.456	13.544	16.65
10	2.1795	5.033	7.955	10.936	13.958	17.00
100	2.381	5.465	8.567	11.675	14.784	17.89
1000	2.402	5.515	8.645	11.780	14.916	18.06
∞	2.4048	5.520	8.654	11.792	14.931	18.07

The following general conclusions may be drawn from Eqs. 9 without actually computing values.

When $r = b$, $S_r = 0$ and $S_\theta = S_z$
When $r = 0$, $S_r = S_\theta = 0.5\, S_z$

In general, S_z will have a greater magnitude than either S_θ or S_r. This may not be true in the vicinity of $r = 0.707\, b$ where S_z is very small while S_θ is positive and S_r is negative. Since we are interested chiefly in maximum tensile and compressive stresses, numerical computations are made for S_z only. For a positive T_0 (cooling), the maximum positive value (tension) of S_z is at $r = b$, and the maximum negative value (compression) is at $r = 0$. These maximums occur at different values of F, depending on B. For the special case of $r = b$, and $B = \infty$, the maximum occurs at $F = 0$ and is equal to

$$\frac{2E\alpha T_0}{1-\mu}\sum_{n=1}^{\infty}\frac{2}{\beta_n^2}$$

which reduces to a simple value, $\dfrac{E\,\alpha\,T_0}{1-\mu}$.

Figure 2 shows maximum stresses at the surface, center, and some intermediate points in percentage of the stress for the above special case as a function of B. From Fig. 2 and what has been stated above, it must be concluded that warming or cooling in air produces only small stresses, compared with immersion in water.

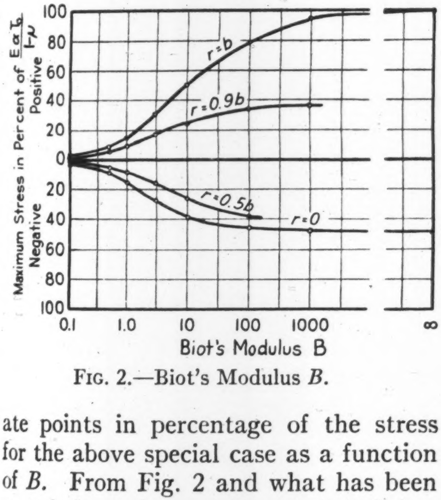

FIG. 2.—Biot's Modulus B.

Figure 3, showing longitudinal stress-time curves for various values of r for $B = 3$, gives a picture of what is taking place. At the beginning, the cylinder is stress free. Very quickly, the surface $r = b$ reaches its maximum stress. Most of the cylinder now has small negative stresses. A little later, the center reaches its maximum negative stress, after which all parts eventually become stress free again. The region in the vicinity of $r = 0.707\,b$ has very little longitudinal stress at any time and although actual computations have not been made, the author has reason to believe that the radial and tangential stresses are also small.

CONCLUSIONS

The special value of $\dfrac{E\,\alpha\,T_0}{1-\mu}$ as the theoretical stress at the surface for $B = \infty$ has been known for a long time, as it can be derived in a very simple manner.

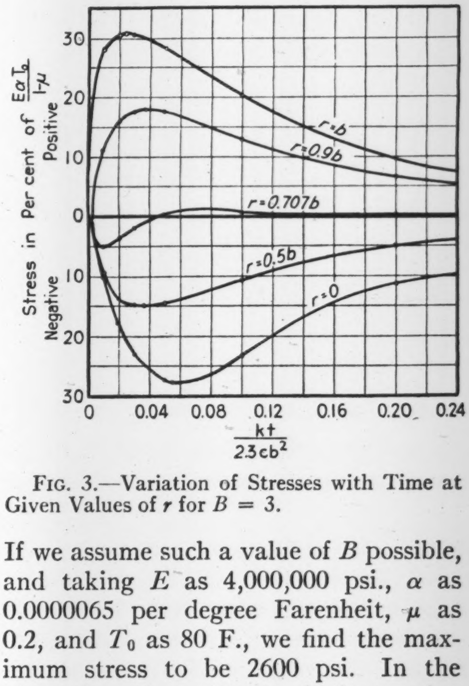

FIG. 3.—Variation of Stresses with Time at Given Values of r for $B = 3$.

If we assume such a value of B possible, and taking E as 4,000,000 psi., α as 0.0000065 per degree Farenheit, μ as 0.2, and T_0 as 80 F., we find the maximum stress to be 2600 psi. In the case of cooling, this would be tension and far in excess of the tensile strength of concrete. The above can be of only theoretical interest because of the impossibility of such a value of B. However, $B = 100$ is possible with good circulation of water and, from Fig. 2, gives a stress at the surface 80 per cent as great. This stress seems to be chiefly a surface effect because one-tenth of the radius beneath the surface we find only $0.35 \frac{E \alpha T_0}{1-\mu}$.

It is realized that it is folly to draw very many conclusions from the above theoretical analysis until more carefully controlled experiments have been conducted. However, from a study of the above curves, together with experimental data obtained by others, the author suggests the following:

1. Cooling in water and heating in air as has been done in wetting-and-drying tests should give about twice as great maximum tension for the same temperature range as cooling in air and warming in water, as is usually done in freezing-and-thawing tests. This may be a factor for the sudden deterioration of concrete in some wetting-and-drying tests. Such analysis may be incorrect for at least three reasons: first, in wetting-and-drying tests the emphasis is not on temperature change, and if the specimens are allowed to remain in air at room temperature for a time after removal from the drying oven and before being placed in the wetting tank, the maximum tension may be greatly reduced. Second, the freezing of at least some of the water in freezing-and-thawing tests may cause severe stresses not accounted for in this paper. Third, the latent heat of fusion of water causes the temperature distribution to deviate from the theoretical.

2. In wetting-and-drying tests, the maximum tension occurs at the surface when placed in water. A few cycles may cause the surface to become inelastic, after which thermal stresses may become practically nonexistent due to the inelastic surface layer providing insulation for the interior. It is possible that this may account for observed decrease in strength of specimens during the first 50 or 100 cycles, after which there is no further decrease. On the other hand, deterioration in freezing-and-thawing tests may start from inside and progress outward during thawing in water. It is also recognized that the disruptive effect of freezing may show itself first on the surface. Therefore, in this case, it is expected that loss of strength would continue with increase of cycles.

3. Stresses produced by heating and cooling in which the specimens are kept submerged in water and the cycles are produced by alternately injecting steam and cold water into the water tanks cannot be calculated by the formulas of this paper. A separate mathematical treatment would be required. Since the temperature of the surrounding water changes gradually, large stresses should not be expected. Experimental investigation shows that in many cases no difference can be detected between the strength of specimens subjected to this heating and cooling and control specimens from the moist room. Maximum tensile stresses would occur at the surface, and then maximum deterioration, if any, should occur in the first few cycles, after which there may not be much effect.

4. From all that has been said, one would certainly conclude that differences noted in the results of the above heating-and-cooling tests compared with freezing-and-thawing tests may be due chiefly to the manner in which the tests are conducted instead of the fact that one test is conducted above the freezing range, as has been assumed by investigators in the past.

5. It must be recognized that the main part of this paper is theoretical, the results are approximations and the conclusions are tentative.

THERMAL VOLUME CHANGE AND ELASTICITY OF AGGREGATES AND THEIR EFFECT ON CONCRETE

By T. F. Willis[1] and M. E. De Reus[1]

Synopsis

This paper describes the methods and results of exploratory tests made in preparation for an investigation of the elastic properties and thermal coefficient of expansion of concrete aggregates commonly used in Missouri, and of the effect of these characteristics of the aggregates on mortar and concrete made from them. Included are:

1. A description of apparatus and methods used.
2. A discussion of the accuracy of the measurements.
3. Results of measurements of modulus of elasticity and thermal coefficient of expansion of:
   (*a*) Specimens of limestone, chert, quartzite, granite, basalt and sandstone, and
   (*b*) Specimens of mortar, made from normal portland cement and crushed sands derived from limestone, chert and quartzite.

The results are discussed and indications pointed out.

In connection with a study of the deterioration of concrete, information was required on the thermal coefficient of expansion and the modulus of elasticity of concrete coarse aggregates commonly used in Missouri and of the influence of these characteristics of the aggregates on the properties of concrete made from them. Investigations of the durability of concrete have indicated that this may be of considerable importance.

While a number of investigations of somewhat similar nature have been reported, neither the results nor the methods are applicable to our problem. Unfortunately, the variation in physical properties of rocks from different sections of the country, even though of similar type and stratigraphical location, precludes the possibility of assuming that values obtained by other investigators are applicable to the rocks of this geographical area.

Also the studies of other investigators have consisted of the determination of the effects of the type of coarse aggregate on the thermal coefficient and modulus of elasticity of concrete. There have been few direct determinations of these properties of the aggregate and their influence on the concrete, and as far as the authors know, no such determinations where the maximum size of the particles available for study was as small as that of one of the principal sources of coarse aggregate, stream gravel. Further, there is only inferential information on the effect of these properties of sands on similar properties of mortar and concrete made from them.

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[1] Research Engineer, and Junior Engineer, respectively, Bureau of Materials, Missouri State Highway Dept., Jefferson City, Mo.

Scope:

As outlined, the investigation contemplates the determination of the modulus of elasticity and thermal coefficient of expansion of the principal coarse aggregates used in Missouri, and a study of the effect of these properties of the aggregates on the same properties of mortar and concrete. However, this report covers only a description of the methods used and results of exploratory tests made in preparation for the major investigation. Tests for thermal coefficient and modulus of elasticity were made on 123 specimens from 7 types of aggregates obtained from 20 sources. Measurement of the same properties were made on mortar specimens manufactured from a normal portland cement and 5 types of sand.

TABLE I.—GRADATION OF SAND.

Tyler Screen	Retained, per cent
No. 4	0
No. 8	20
No. 14	40
No. 28	60
No. 48	80
No. 100	95
No. 200	100

PREPARATION OF SPECIMENS

Aggregate.—The test specimens of aggregate consisted of cylindrical cores 1 in. in diameter by 2 in. long drilled[2] from specimens of the aggregate to be tested. The ends of the cylinders were ground to smooth planes perpendicular to the axis.

Mortar.—Mortar cylinders were formed in cylindrical metal molds 1 in. in diameter by 2 in. long. The ingredients of the mortar were a normal portland cement, sand manufactured from the remainder of a specimen after drilling a core, by crushing and grinding so that it had the gradation shown in Table I and water which was added in sufficient amount to give the required water-cement ratio and to compensate for the 24-hr. absorption of the sand.

MEASUREMENT OF THERMAL COEFFICIENT

The apparatus designed and constructed for measuring the linear thermal expansion is shown diagrammatically in Fig. 1. The specimens are placed in an oil bath surrounded by a water bath, which in turn is surrounded by an insulating box. The apparatus accommodates two specimens at a time. Each specimen stands vertically in the bath. An optical lever (lever arm 1 in.) is placed so that two of its legs (those forming the pivot) rest on Nilvar posts and the third on the specimen.[3] The

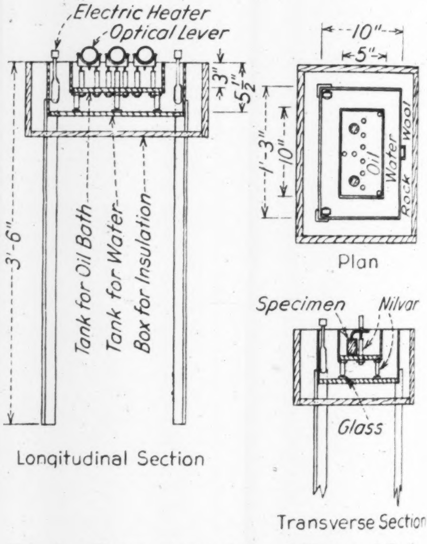

FIG. 1.—Temperature Control Unit and Optical Levers Used for Measuring Thermal Expansion.

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[2] For drilling these cores a small ceramic drill, having a cylindrical brass drill bit and using emery dust paste as the abrasive, was found to be much faster than the diamond core drill.

[3] A microscope slide cover glass was interposed between the specimen and the leg of the optical lever, for in order to obtain consistent results the legs of the optical lever must rest on surfaces which are absolutely plane.

vertical movement of the specimen, which occurs as the temperature is varied, is measured by observing through a precise level the image, reflected by the mirror[4] of the optical lever, of a vertical scale placed 20 ft. from the mirror.

Each specimen was tested over the range 37 ± 3 F. to 140 ± 5 F., and the change in scale reading from the initial reading plotted against temperature. Values for 40 and 140 F. were interpolated from this curve and the mean coefficient for this range was calculated from the equation:

$$C = \frac{yl}{2xth} + K$$

where:

C = the coefficient of linear expansion in inches per inch per deg. Fahr.,

y = the deflection of the scale image in millimeters,

l = the lever arm of the optical lever (1 in.),

x = the normal distance from the mirror to a plane, parallel to the mirror, passing through the scale (232 in.),

t = the rise in temperature in deg. Fahr.,

h = the height of the specimen in millimeters, and

K = a constant.

The constant K is equal to the coefficient of expansion of Nilvar plus or minus any characteristic distortion of the apparatus caused by temperature change. Based on a number of measurements made on Nilvar specimens of known coefficient (5.0×10^{-7}), K was found to be -2.0×10^{-7}.

Consideration of the possible errors involved in the measurements shows that the calculated coefficients are probably accurate to plus or minus 2.0×10^{-7}. This figure is in accord with the results of check determinations on the same specimen.

MEASUREMENT OF MODULUS OF ELASTICITY

Since it is difficult to obtain large representative specimens of a gravel aggregate on which the stress-strain relationship may be measured, a method was devised for accurately measuring the deformation of an individual specimen on a gage length as short as 1 in. The method consists essentially of the microscopical measurement of the relative movement of two lever arms, one pivoted and the other fixed on a cylindrical specimen, 1 in. in diameter. The design of the lever, which is of the compressometer type, is shown in Fig. 2. The upper arm is fixed to the specimen at three points while the lower arm, which transmits the average deformation of two opposite sides of the specimen to the brass plates at the end of the arms, is pivoted on the specimen. In order

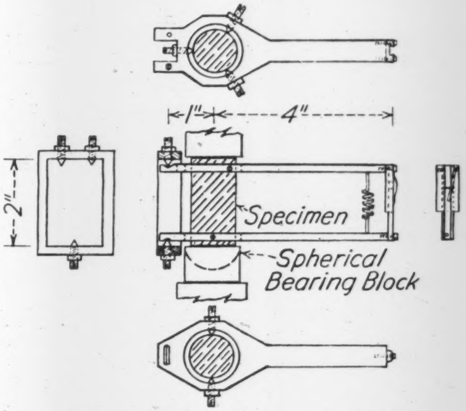

FIG. 2.—Lever Type Compressometer.

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[4] The front-surfaced mirrors of the original equipment were not sufficiently plane to produce an undistorted image in the telescope, which had a magnification of 40 diameters, and therefore selected plate glass mirrors were substituted.

to keep the sharp pointed screws from penetrating into the specimen and subsequently working loose, a thin piece of watch spring steel is placed between the points and the specimen, thus giving a blunt point contact with the specimen but still allowing the lever to swing freely. The rectangular ring serves as the fulcrum of the lever system.

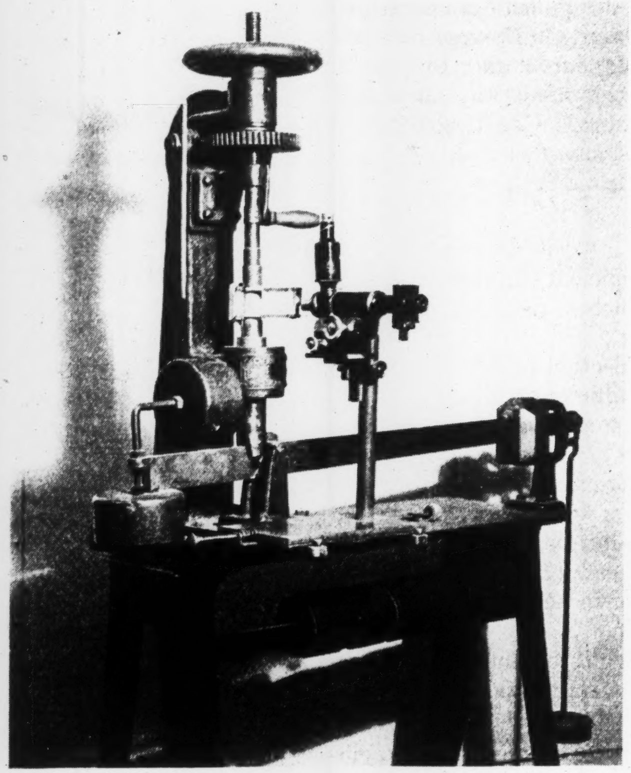

FIG. 3.—Showing Assembly of Apparatus.

The relative displacement of the brass plates with respect to each other is measured by means of a microscope equipped with a vertical illuminator, an 8-mm. objective, and a filar micrometer eyepiece. The total magnification of the system is 1550, consisting of 4.95 times for the mechanical lever and 313 times in the microscope. With this magnification, one graduation on the drum of the filar micrometer is equal to a deformation of 0.000003 in. in the gage length of the specimen. In making measurements the cross-hair of the eyepiece is easily set to plus or minus one-half drum graduation.

A Riehle briquet molding machine (see assembly of apparatus in Fig. 3) is used for loading the specimen. The specimens are loaded to a total load of 600 kg. (1680 psi. for a specimen 1 in. in diameter), generally in increments of 100 kg., except that the first two and the last two increments are of 50 kg. The load is applied manually at the rate of 100 kg. every three minutes. The stress-strain relationships were determined for both an increasing and a decreasing load, and check determinations were made for each specimen.

For each test, the deformation in drum units was plotted against the load in kilograms, a smooth line drawn through the points plotted, and the value of the modulus calculated from the following formula:

$$E = \frac{4\,KLM}{\pi\,D^2NV} \text{ kg. per sq. mm.}$$

or multiplying by 1422 to convert to pounds per square inch,

$$E = 1811\,\frac{KLM}{D^2NV} \text{ psi.}$$

where:

E = modulus of elasticity,
K = load in kilograms,
L = gage length in millimeters,
M = mechanical advantage of lever system (4.95),
D = diameter of specimen in millimeters,
N = number of drum graduations, and
V = value of one drum graduation (0.0004 mm.)

Considering the magnitude of the possible errors in the various measurements involved, the probable error of the reported values of the modulus of elasticity does not exceed 3 per cent; and this figure is in accord with the results obtained by check determinations of the modulus, which have shown a difference for the value of the modulus as large as 15 per cent but on the average have shown a difference of only 5 per cent.

DATA AND DISCUSSION

AGGREGATES

Thermal Coefficient of Expansion:

For all the aggregate specimens, except some of the limestones, the linear expansion plotted against temperature was essentially a straight line. The graphs of these exceptions were distinctly curves and some were curved sufficiently to indicate that the specimens have the peculiar property of exhibiting "minimum length."[5] In Fig. 4 the graph of the specimen having the greatest curvature is shown.

The upper section of Fig. 5 shows the thermal coefficients of all the aggregate specimens tested, classified by type and source.

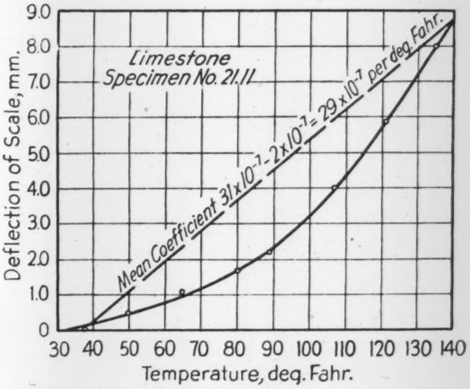

FIG. 4.—Illustrating the Maximum Curvature Observed for the Thermal Expansion Curve.

It is noteworthy that all values for the three aggregate types, chert, quartzite and sandstone, composed essentially of silica fall in a narrow range, from 6 to 7×10^{-6}. In fact, a statistical analysis of these data, based on the assumption that they are all derived from the same statistical universe, shows the distribution to approximate that predicted by the law of probability. In other words, it is indicated that the variation in the observed thermal coefficients of all the specimens of chert, quartzite, and sandstone may be primarily due to instrumental errors and that the true values for all these highly siliceous rocks are, for all practical purposes, the same.

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[5] The phenomenon of minimum length in tests of specimens of marble was observed by W. H. Souder and P. Hidnert, "Thermal Expansion of Insulating Materials," *Scientific Paper No. 352*, Nat. Bureau Standards, p. 411 (1919).

With a few exceptions, the thermal coefficients of all the limestone specimens fall in the range of 2 to 4 × 10^{-6}, a very appreciable decrease from the values for the siliceous materials. Even the three thermal coefficients of limestones above this range are lower than the lowest coefficients exhibited by any of the siliceous materials.

The other three rock types tested, basalt, granite and dolomite, which occur as minor proportions of the aggregates from a few sources, have thermal coefficients intermediate between those of the siliceous materials and the limestones.

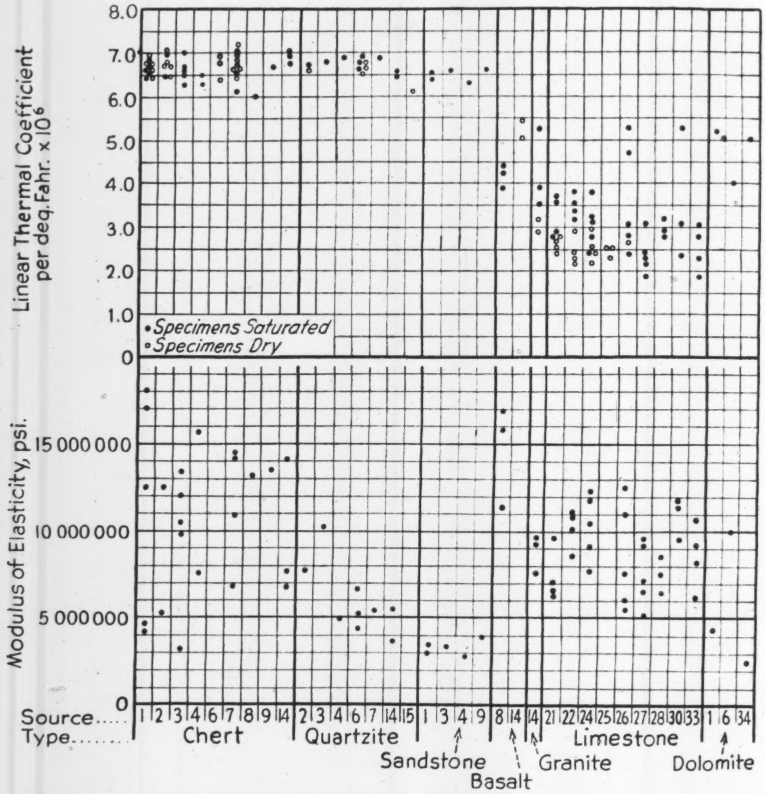

FIG. 5.—Values of Modulus of Elasticity and Linear Thermal Coefficient of Various Aggregates (Each Point Represents One Specimen).

Modulus of Elasticity:

None of the materials dealt with in this investigation are truly elastic, the total deformation due to load being made up of plastic as well as elastic deformation.[6] However, when rate of loading is constant, the relation of the unit deformation to the unit stress is a comparable characteristic of each material. The moduli of elasticity, so-called, reported in this investigation are the slopes of the tangents to the stress-strain curves at a stress of 1680 psi.

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[6] A majority of the specimens exhibited a straight line for the stress-strain relationship upon the application of load, but in practically every case more or less hysteresis was noted upon the release of load; however, in a few instances full recovery of the deformation was achieved by those specimens which had the higher moduli.

The values for this characteristic of the various aggregates tested are shown in the lower section of Fig. 5. It is obvious that even for rocks of the same type and from the same source the modulus varies over a wide range. Particularly is this true of the chert specimens. Specimens from one deposit varied from 5.0 to 18.0 × 10^6. In all cases in which chert specimens showed a modulus of less than 10.5 × 10^6, the specimens were obviously porous. The aggregate from most deposits that are predominantly chert would be composed largely of particles having a modulus greater than 10.5 × 10^6.

The limestone specimens also showed considerable variation, although in general the moduli were somewhat more uniform than the cherts. Also these tests indicate that, taken as a group, the limestone aggregates will have lower moduli than those of the preponderance of particles in the aggregates from chert deposits.

MORTAR SPECIMENS

For the mortar tests, five sands were prepared by crushing specimens which had previously been cored and tested for thermal coefficient and modulus of elasticity. The parent material of these sands consisted of two limestones and two cherts (one of each having a low modulus of elasticity and the other a high modulus) and a quartzite. Three series of tests were made with each of these five sands, the proportions of the mortar being as follows:

(*a*) Mix 1:2.4, water-cement ratio 0.70
(*b*) Mix 1:3.6, water-cement ratio 0.70
(*c*) Mix 1:3.6, water-cement ratio 0.85

Also tests were made of the neat cement with a water-cement ratio of 0.40 and 0.55. All specimens were cured one day in the moist closet and 27 days in water, and tested at 28 days.

Thermal Coefficient:

The tests for thermal coefficient of the neat cement gave rather erratic results. Neither the duplicate tests on the same specimens, nor the individual tests on the different specimens of the same series, checked as well as the mortar tests. The cause for this is being investigated in a series of tests now under way. Based on the tests already made, the most that can be said is that for the cement used and water-cement ratios of 0.40 to 0.55, the thermal coefficient lies in the range of 6.4 to 7.7 × 10^{-6}.

TABLE II.—RELATION BETWEEN THERMAL COEFFICIENT OF MORTAR AND THAT OF PARENT MATERIAL.

Parent Material		Thermal Coefficient of Mortar × 10^6			
Type	Thermal Coefficient ×10^6	Mix (Abs. vol.) .... 1:2.4 Water-cement ratio, ... 0.70	1:3.6 0.70	1:3.6 0.85	Avg.
Quartzite...	6.7	6.7	6.6	6.6	6.63
Chert.......	6.5	6.5	6.4	6.8	6.57
Chert.......	6.6	6.4	6.3	6.7	6.47
Limestone...	4.7	4.8	4.4	4.8	4.67
Limestone...	2.9	3.9	3.6	3.8	3.77

The tests on mortars gave consistent results and showed that over the range tested (40 to 140 F.) the relation between temperature and linear expansion is essentially linear. The results of the tests are shown in Table II. It is at once evident from the data that the characteristic thermal expansion of the mortar is closely related to that of the sand from which it is made; in fact for the mortars and sands tested, controlled by it. The mortars made from the three siliceous aggregates have thermal coefficients almost identical with those of the aggregates and probably somewhat lower than that of the neat cement. The coefficients of the mortars made from the limestone with the higher coefficient were also almost identical with that of the aggregate, and were definitely lower than that of the neat cement. The coefficients of the mortars, made from the limestone with lowest coefficient, had the smallest value of any obtained in the mortar series. However, they were materially greater than that of the sand. This would indicate that there is some minimum value for the thermal coefficient of a mortar, regardless of how small the coefficient of the sand may be.

Considering the average for all the sands, there is an indication from the very limited data available that the effect of the aggregate is increased as its proportion in the mortar is made greater; also that the coefficient for the wetter mixtures is greater. Neither of these points can be considered as proven.

Modulus of Elasticity:

As previously stated, the reported moduli of elasticity are those derived from the stress-strain relationship for the first loading, and for an increasing load. A statistical study showed that there was no difference between the results obtained from the first loading and those obtained from the second loading, provided the specimens were not stressed in excess of the elastic limit. However, it should be pointed out that there was a distinct difference in the results obtained from an increasing load as compared with those obtained from a decreasing load, the modulus being somewhat greater for a decreasing load.

For the neat cement, the determinations of the modulus were much more consistent than were the determinations of the thermal coefficients. Good checks were obtained on companion specimens as well as on consecutive tests on the same specimen. For a water-cement ratio of 0.40, the modulus was 3.8×10^6 and for a water-cement ratio of 0.55, the modulus dropped to 2.7×10^6.

The results of the tests on mortar specimens also indicate that an increase of the water-cement ratio will cause a decrease of the modulus of the mortar; but the data indicate too, that the modulus of the mortar is influenced by the character of the sand from which it is made. The results of the mortar tests are shown in Table III. It is at once evident that the correlation between the modulus of the mortar and of the parent material of the sand is not so good as in the case of the thermal coefficient. This lack of correlation may be partially due to the fact that two of the materials, quartzite and one of the cherts, were highly porous; that the sands obtained by grinding these materials were considerably less porous and may have had higher moduli than those of the parent material.

TABLE III.—RELATION BETWEEN MODULUS OF ELASTICITY OF MORTAR AND THAT OF PARENT MATERIAL.

Parent Material		Modulus of Elasticity of Mortar $\times 10^{-6}$				
Type	Modulus of Elasticity $\times 10^{-6}$	Mix (Abs. vol.).... Water-cement ratio,.....	1:2.4 0.70	1:3.6 0.70	1:3.6 0.85	Avg.
Chert.....	14.4		4.8	4.8	4.1	4.57
Quartzite	6.7[a]		4.2	4.2	3.6	4.00
Chert.....	6.8[a]		4.1	3.6	3.7	3.80
Limestone.	11.2		3.8	4.4	3.8	4.00
Limestone.	6.0		2.8	3.2	2.6	2.87

[a] Specimens on which modulus was measured were porous. Modulus of sand particles is probably somewhat higher than that of parent material.

Other investigators have shown that for concrete, the modulus of elasticity is definitely related to the strength. For the mortars in these tests, a graph of the modulus, plotted against compressive strength, results in a greatly dispersed set of points, showing poor correlation between these factors. However, when the moduli of the mortars are plotted against an empirically derived function[7] including both strength and modulus of the sand, fair correlation is shown. Thus it is indicated that the modulus of elasticity of a mortar is related to both the strength of the mortar and the modulus of the sand from which it is made.

Plastic Flow:

Plastic flow of the mortar under stress of 1680 psi. for one hour was measured on two specimens of each set. The average results are shown in Table IV. Trends are discernible but further tests are required to establish their validity.

Following the reports of other investigations that the plastic flow of concrete under stress is closely related to strength, the results for these characteristics of the mortar specimens were plotted. The graph showed a definite tendency for the plastic flow to be inversely proportional to the strength, but the points were so scattered that the degree of correlation between plastic flow and strength alone, was obviously low. Further study revealed that there is a much closer relation between plastic flow of the mortar and its modulus of elasticity (see Fig. 6).

TABLE IV.—PLASTIC FLOW OF MORTAR UNDER STRESS OF 1680 PSI. FOR 1 HR.

Parent Material		Plastic Flow of Mortar, units $\times 10^{-6}$ per unit		
Type	Modulus of Elasticity $\times 10^{-6}$	Mix (Abs. vol.) ...... 1:2.4 Water-cement ratio, .. 0.70	1:3.6 0.70	1:3.6 0.85
Chert	14.4	24	30	40
Quartzite	6.7[a]	36	50	38
Chert	6.8[a]	30	56	52
Limestone	11.2	40	35	56
Limestone	6.0	58	60	92

[a] Specimens on which modulus was measured were porous. Modulus of sand particles is probably somewhat higher than that of parent material.

CONCLUSIONS

Inexpensive apparatus has been devised for measurement of the thermal coefficient of expansion and the modulus of elasticity of relatively small particles of aggregate. The indicated accuracy of tests made with this apparatus is plus or minus 0.0000002 for thermal coefficients and plus or minus 3 per cent for modulus of elasticity.

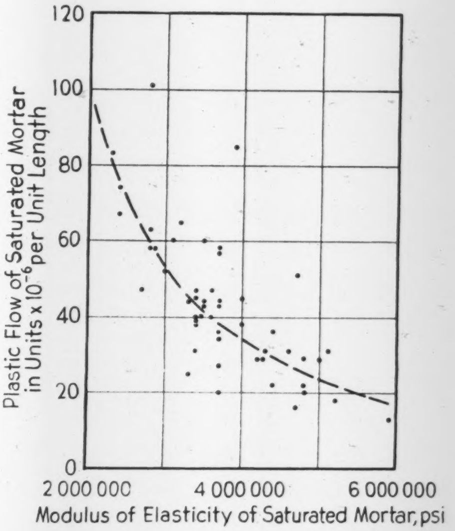

FIG. 6.—Plastic Flow of Mortar Under Stress of 1680 psi. for 1 hr. (Each Point Represents a Single Test on an Individual Specimen).

Tests on the two principal types of coarse aggregate used in Missouri, limestone and chert, show:

1. That the thermal coefficient of expansion of limestone is materially smaller than that of chert.

2. That the modulus of elasticity of both limestone and chert is highly variable, even for material from the same

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[7] The empirical relation used is $E_m = K\sqrt{E_a S}$.

where:

E_m = modulus of elasticity of mortar,
E_a = modulus of elasticity of aggregate,
S = compressive strength of mortar, and
K = a constant.

However, the data are too few to state that this function is quantitatively correct.

source, but that, in general, the modulus of limestone from any one deposit is more uniform and considerably smaller than the modulus of the preponderance of the chert from any single source.

The data on the mortars are too limited to permit any very definite conclusions. However, it is indicated that:

1. The thermal coefficient of the sand is one of the principal determinants of the thermal coefficient of a mortar made from it.
2. The modulus of elasticity of a mortar specimen is affected by the modulus of the sand contained in the mortar and is probably a function of this and the strength of the specimen.
3. The plastic flow of a mortar is closely related to its modulus of elasticity.

DISCUSSION

MR. F. B. HORNIBROOK.[1]—In a concrete in which the large aggregate has a thermal coefficient of volume change considerably different from that of the cementitious material, will that difference in expansivity become unduly destructive in freezing-and-thawing cycles in which the material is subjected to large thermal shock? In addition to the boundary effects associated with large thermal shock as discussed by Mr. Pickett in his paper on the effect of Biot's modulus,[2] is it not possible that differences in coefficients of volume change of the constituent materials of the concrete may be the cause of some of the disintegration in which there is a separation of mortar and large aggregate?

MESSRS. T. F. WILLIS[3] AND M. E. DEREUS[3] (*authors' closure by letter*).—We believe it entirely possible that a difference in the thermal coefficient of the coarse aggregate as compared with that of the cementitious material may affect the reactions of concrete to freezing and thawing. In fact, the outline of the major investigation, to which the experiments described in this paper are preliminary, contemplates an investigation of this point.

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[1] Associate Materials Engineer, National Bureau of Standards, Washington, D. C.

[2] See p. 913.

[3] Research Engineer, and Junior Engineer, respectively, Bureau of Materials, Missouri State Highway Dept., Jefferson City, Mo.

THE EFFECT OF VARIATIONS IN METHOD UPON THE RESULTS OF FREEZING AND THAWING MORTARS

By Bert Myers[1]

Of the devices which nature uses to destroy rocks, alternations of freezing and thawing seems to be one of the most effective. There is some evidence that the same is true for portland cement concrete. Therefore, since modern cooling equipment makes it convenient to accomplish freezing and thawing in the laboratory, it is natural that investigators of the durability of concrete and concrete aggregate should use freezing-and-thawing tests in their studies. Such tests are being used in an increasing number of laboratories.

The procedure followed in making the test in various laboratories has varied quite widely as to rate of cooling, rate of heating, and moisture condition of the specimen. It is only recently that any attempt has been made to standardize these procedures.

It has been assumed that the more rapidly temperature changes are accomplished, the more destructive the effect produced. So far as this author has learned no extensive work has been done to determine the effects of variations in procedure upon the results of the test.

It is obvious that no practical laboratory test for durability can duplicate natural weathering conditions. However, the real value of any durability test will depend upon the reliability with which predictions can be made from the results obtained. It is hoped that in the standardization of such a test the probable effects of possible variations in method will be studied to the end that the test as finally standardized will provide a reliable basis for predicting the relative durability of concrete and concrete materials.

This paper reports a few data which may be of some value in such studies. They seem to indicate that while the destructive effect of freezing may be proportional to the rate of cooling, the effect of heating may be more nearly inversely proportional to the rate at which the temperature is raised.

Object:

This study made by the Iowa State Highway Commission had two objectives:

1. To determine the effect of some variations in method of freezing and thawing upon the strength and degree of surface disintegration of mortar specimens.
2. To determine which of the methods used is most nearly comparable in effect to that of natural exposure.

The second phase of the problem, which involves the exposures of specimens out of doors to be tested later, will require several years and cannot be reported upon at this time.

Scope:

Four different methods of freezing-and-thawing treatment were applied to groups of mortar prisms representing three brands of cement. The proportions, kind of aggregate, water-cement ratio, curing treatment, and age were the same for all specimens. The effect of 100 cycles of each method upon the flexural strength, compressive strength, and weight of the specimens was determined.

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[1] Engineer of Materials and Tests, Iowa State Highway Commission, Ames, Iowa.

TABLE I.—SIEVE ANALYSIS OF SAND.

Sieve	Passing, per cent
No. 4	98
No. 8	88
No. 16	72
No. 30	41
No. 50	9
No. 100	2
Fineness modulus	290

TABLE II.—SOUNDNESS TESTS OF SAND.

Method	Number of Alternations	Weighted Average Loss, per cent
Sodium sulfate	5	1.350
Magnesium sulfate	5	1.897
Freezing and thawing	16	1.691

TABLE III.—MINERALOGICAL COMPOSITION OF SAND, PER CENT.

	Retained on No. 16 Sieve	Passing No. 16 Sieve	Whole Sample
Quartz	23.7	81.2	65.2
Chert	2.8	0.8	1.4
Limestone	2.3	0.1	0.7
Shale	0.1	....	....
Sandstone	1.0	....	0.3
Quartzite	0.4	1.9	1.5
Feldspar	8.1	6.9	7.3
Granite rock	21.3	4.0	8.8
Basic rock	34.0	4.9	13.0
Felsite	6.3	....	1.8

Size and Composition of Specimens:

The specimens were 2 by 2 by 14-in. prisms. The weight proportions were one part cement, two parts sand, 0.422 parts water. The aggregate was a durable natural sand. Tables I, II, and III show characteristics of this sand. The cements were normal portland cements of brands commonly used in Iowa. Tables IV, V, VI and VII give the results of tests of the cements. There were 3 specimens for each cement for each method of treatment, making a total of 36 frozen and thawed.

TABLE IV.—PHYSICAL TESTS OF CEMENTS.

Cement	Time of Setting, Vicat Method, hr.: min.		Water for Normal Consistency, per cent	Tensile Strength, psi.		Passing, per cent		Surface Area, Wegner, sq. cm. per g.
	Initial	Final		7 days	20 days	No.200 Sieve	No.325 Sieve	
X	2:50	4:20	24.5	352	422	95.1	91.2	1690
Y	2:25	4:35	24.5	398	468	97.7	89.4	1600
Z	3:15	5:40	26.5	335	442	97.4	92.9	1670

TABLE V.—OXIDE COMPOSITION OF CEMENTS.

Cement	Loss on Ignition	Oxide Composition, per cent					
		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
X	0.97	21.60	3.48	4.14	64.74	3.01	1.80
Y	1.80	19.68	2.37	6.55	63.76	3.65	1.74
Z	2.84	20.08	2.74	4.18	63.74	4.10	1.60

TABLE VI.—COMPUTED COMPOUNDS OF CEMENTS.

Cement	Calculated Compound, per cent				
	C_3S	C_2S	C_3A	C_4AF	$CaSO_4$
X	61.0	16.0	5.0	10.6	3.1
Y	57.0	13.5	13.5	7.3	2.9
Z	70.0	4.9	6.6	8.2	2.9

TABLE VII.—AUTOCLAVE EXPANSION OF CEMENTS.

Cement	Expansion During 5 hr. in Autoclave (3 hr. 420 F.)		
	First Cycle	Second Cycle	Third Cycle
X	+0.086	+0.123	+0.146
Y	+0.647	+0.839	+0.925
Z	+0.180	+0.250	+0.297

Curing Treatment:

At the beginning of the freezing-and-thawing treatment the samples were 12 months old. They had been cured in the molds in a moist closet for one day, in water for three months, and in moist air for 9 months.

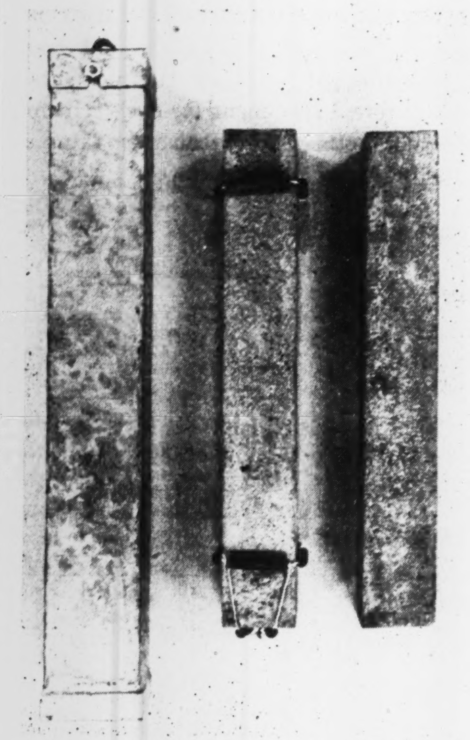


FIG. 1.—Showing Container and Method of Spacing Specimen in Container.

Freezing-and-Thawing Methods:

During the freezing and thawing each specimen was contained in a 2.5 by 2.5 by 18-in. metal can with its long axis vertical. A uniform space of 0.25 in. between each side of the prism and the corresponding wall of the container was maintained by short sections of $\frac{9}{32}$-in. rubber tubing fastened to the specimen with cotton string. The same space was maintained below the bottom of the specimen in the same way. The can and spacing device are shown in Fig. 1.

Freezing was accomplished by placing the container in a circulating cooling solution maintained at a temperature between −10 and 5 F. The depth of immersion was such that the top of the specimen was 2 in. below the level of the cooling solution surrounding the container. In two of the methods of thawing (methods A and C), the containers were fully immersed in a water bath the temperature of which was automatically controlled at 65 to 70 F. In method B the container was exposed to the air in the laboratory.

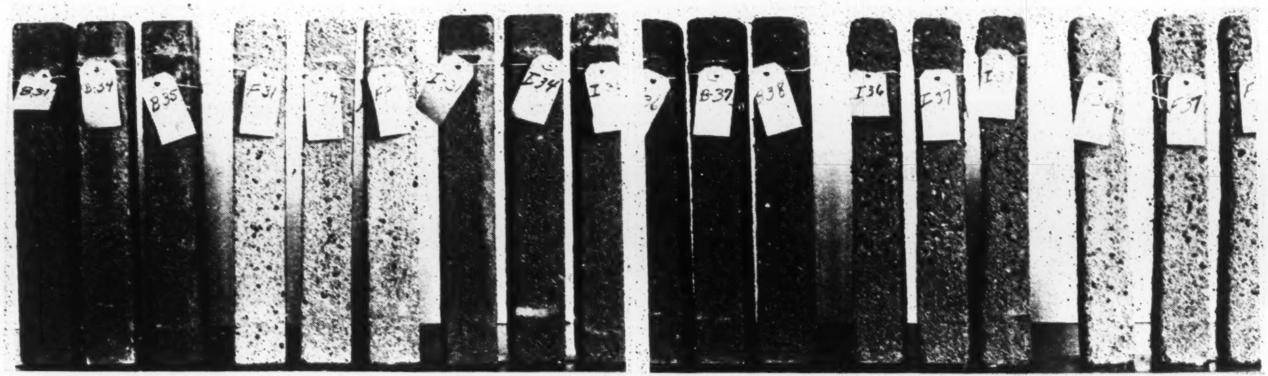
In method D the container was immersed in the water bath to such a depth that the top of the specimen was 2 in. below the level of the water but no water entered the container. Table VIII shows an outline of these methods and gives rates of change of temperature of the specimens.

TABLE VIII.—OUTLINE OF FREEZING-AND-THAWING METHODS.

	Freezing				Thawing			
	Method A	Method B	Method C	Method D	Method A	Method B	Method C	Method D
Space between specimen and container filled with	Water	Water	Air	Air	Water	Water	Water	Air
Container surrounded by	Cooling solution				Water	Lab. Air	Water	Water
Time required for 60-deg. temperature change, min.	37	37	142	142	34	211	26	144
Time required to cool from 70 to 30 F., min.	17	17	49	49	..	..	..	...
Time required to warm from 0 to 32 F., min.	..	..	..	..	19	43	6	61

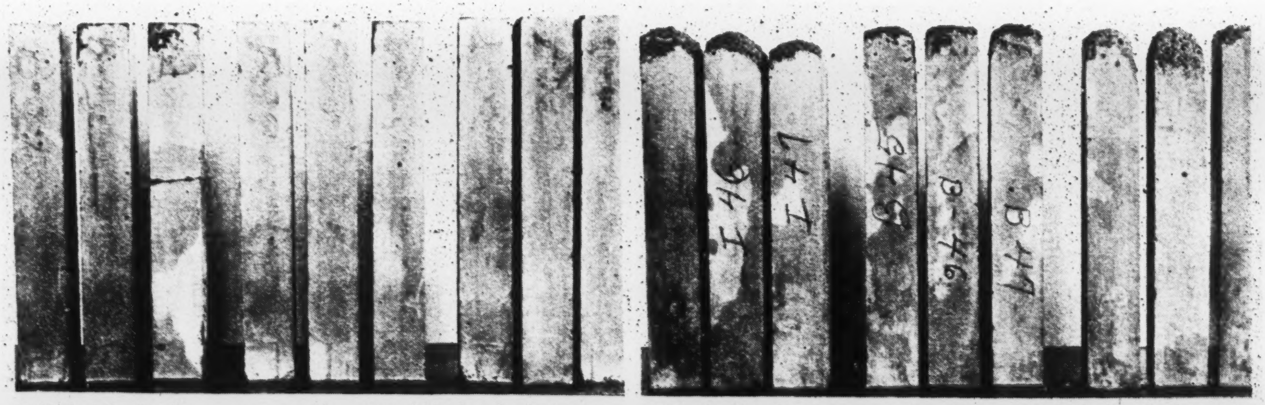
Figure 3 shows time-temperature curves for the various methods of treatment.

At the end of each 10 cycles, the specimens subjected to method D were soaked for 24 hr. in water at 70 F. without being removed from the container. The water was poured from the can at



(*a*) Method A. Specimens are arranged as to brands of cement as follows: *X*, *Y*, *Z*.

(*b*) Method B. Specimens are arranged in groups of 3 by brands of cement as follows: *X*, *Y*, *Z*.



(*c*) Method C. Specimens are arranged in groups of 3 by brands of cement as follows: *X*, *Y*, *Z*.

d) Method D. Specimens are arranged in groups of 3 by brands of cement as follows: *Z*, *X*, *Y*. The condition of the upper ends of the specimens is due to moisture condensed in the bottom of the container during the first 50 cycles.

FIG. 2.—Condition of Specimens After 100 Cycles.

the end of the soaking period. At the end of 50 cycles the specimens were removed from the containers and their ends were reversed. At this time it was discovered that a considerable quantity of water had condensed in the bottom of the can during the 10 cycles between soaking periods. This caused a great difference in conditions between the lower end of the specimen and the remainder of its length. During the last 50 cycles the condensed water was removed after each cycle. The appearance of the specimens at the end of 100 cycles of the four methods is shown in Fig. 2.

TABLE IX.—EFFECT OF 100 CYCLES UPON STRENGTH.

Method of Treatment	Time Required for 60-deg. Temperature Change, min.		Percentage of Normal Strength					
			Flexural			Compressive		
	Freezing	Thawing	Cement X	Cement Y	Cement Z	Cement X	Cement Y	Cement Z
A.............	37	34	19	51	15	41	50	31
B.............	37	211	14	19	4	38	38	23
C.............	142	26	95	91	47	99	101	69
D.............	142	144	100	93	55	99	100	83

TABLE X.—EFFECT OF 100 CYCLES UPON WEIGHT.

Method of Treatment	Time Required for 60-deg. Temperature Change, min.		Loss in Weight, per cent		
	Freezing	Thawing	Cement X	Cement Y	Cement Z
A......	37	34	2.46	6.15	3.94
B......	37	211	8.73	17.51	19.27
C......	142	26	0.14	0.11	0.09
D......	142	144	2.10	4.00	4.94

Tests After Freezing and Thawing:

At the completion of the last cycle the specimens were soaked in water at 70 F. for 24 hr. They were then removed from the containers, washed, weighed and tested as simple beams, loaded at the one-third points with a span of 12 in. between bearings. The broken ends of the beams were capped with neat cement and tested in compression as modified cubes.

Results:

Table IX shows the effect of 100 cycles of each method upon strength. The values given are the strengths of the specimens at the end of the treatment expressed as percentage of the strength of similar specimens of the same age that had not been frozen and thawed. Table X shows the degree of surface disintegration caused by 100 cycles of each treatment. The values given are the losses in weight expressed as percentage of the original weight of the specimen. The losses in weight for method D are not typical for this method since one end of the specimen was exposed to more or less water during 50 cycles. The effect of this moisture is shown in Fig. 2 (*d*) where the upper ends of the specimens show serious surface disintegration while the remainder of the specimen shows little or no loss.

Discussion of Results:

The results reported in Tables IX and X indicate the following:

1. Flexural strength is more sensitive than compressive strength to variations in method of freezing and thawing.

2. Rapid cooling combined with slow heating caused the greatest loss of both weight and strength.

3. Variations in the rate of cooling had a greater effect than the rate of heating upon loss of strength.

4. The indicated relative durability of the mortar produced from the differ-

ent brands of cement depends upon the method of test.

Flexural strength data for methods A and B indicate that cement Y produces mortar considerably more durable than cement X, whereas the same data for methods C and D indicate that the mortar made from cement X is slightly more durable than that produced from cement Y. All the data for strength indicate that cement Z produces mortar much less durable than either of the others. However, method A caused almost twice as much loss in weight for cement Y as for cement Z.

A study of Fig. 3 with Table X indicates that the loss in weight was approximately proportional to the time the specimen remained at a temperature of about 32 F. during the thawing cycle.

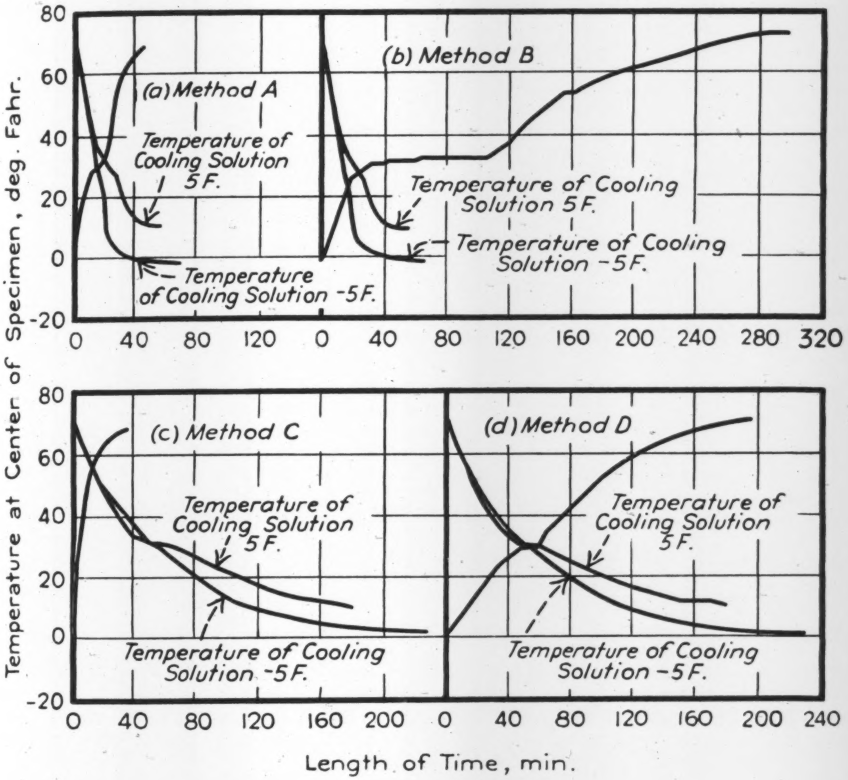


FIG. 3.—Rate of Freezing and Thawing.

Conclusions:

The results of this study seem to lead to the following conclusions:

1. In order to secure comparable results from freezing-and-thawing tests it is necessary that the conditions of tests be controlled carefully.

2. If slight differences in effect are taken as indications of the relative durability of mortars or one of their constituents the conclusions reached are likely to depend upon the details of the method of test.

3. It is highly desirable that extensive work be done in an effort to correlate the effects of laboratory freezing and

thawing with the effects of natural weathering and to determine what laboratory method gives results most nearly parallel to those of natural weathering.

Acknowledgments:

The specimens were prepared in the Commission's Des Moines laboratory under the direction of A. F. Faul. The tests of the specimens and the materials were made in the Ames laboratory under the direction of James W. Johnson. The autoclave tests of the cements were performed by the Portland Cement Association through the kindness of H. F. Gonnerman.

SELECTION OF AGGREGATES FOR CONCRETE PAVEMENT BASED ON SERVICE RECORDS

By Curtis Cantrill[1] and Louis Campbell[1]

Synopsis

This paper presents the service record of various aggregates as indicated by a concrete pavement condition survey. The purpose of the investigation was to determine (1) aggregates having unsatisfactory service records, and (2) standard tests which would eliminate future use of these aggregates.

The condition survey consisted of a classification of all types of cracking and surface disintegration, which was then correlated with construction data and laboratory tests. Analyses of the data established aggregates having unsatisfactory service records.

Examination of the concrete in which certain aggregates were incorporated showed that a large decrease in flexural strength had occurred. This condition was especially noticeable in chert gravel pavement after a period of exposure varying from 2 to 5 yr. Flexural tests on laboratory specimens manufactured from chert gravel and subjected to 40 cycles of freezing and thawing in the presence of water substantiated this observation. A decrease in flexural strength as high as 100 per cent was observed for specimens containing chert gravel obtained from the Tennessee River, 15 miles above the mouth. Chert gravel from the Cumberland River at Clarksville, Tenn., showed results slightly better. This material has successfully passed all standard tests for soundness and wear. Field specimens of chert gravel concrete have always passed the usual strength requirements.

This investigation indicates that failure and disintegration of concrete pavement throughout the western part of the state resulted from the use of chert gravel obtained from the Tennessee and Cumberland Rivers and that the fine aggregate did not contribute to this failure. Chert gravel may be eliminated by standard tests outlined in this paper.

Crushed sandstone resulted in satisfactory pavement when used with Ohio River sand, whereas when used with sand manufactured from sandstone it resulted in unsatisfactory pavement.

Previous to July 1, 1937, the Kentucky Department of Highways constructed 183 projects, or approximately 1100 miles of concrete pavement. A number of the projects have given excellent service while others have failed, necessitating expensive replacements. Failures due to subsoil conditions, drainage, etc., have occurred but have been eliminated from the comparisons of the service record of aggregates. The predominant failures take the form of progressive scale followed by disintegration of the concrete. This investigation was undertaken in an effort to eliminate, or

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[1] Senior Materials Engineer, and Materials Engineer, respectively, Kentucky Department of Highways, Frankfort, Ky.

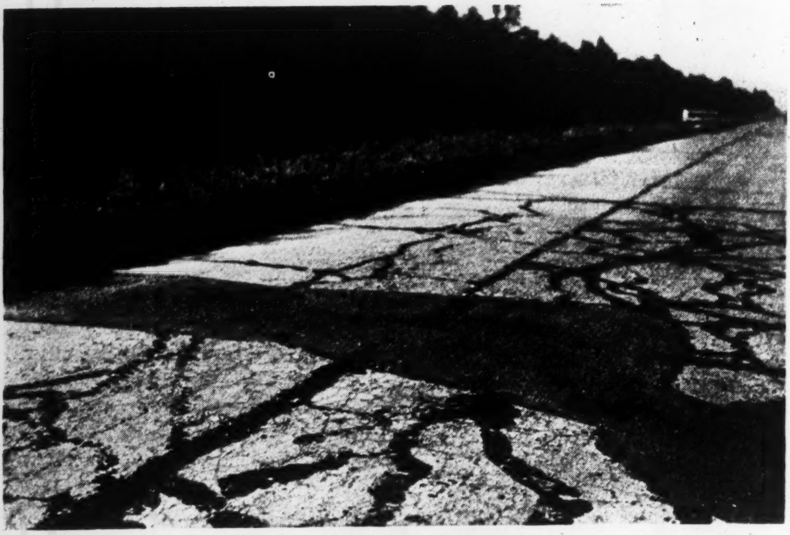

FIG. 1.—Disintegrated Pavement.

Map cracking well developed. Tennessee River gravel—O.R.B.T. sand. Age, 5 yr

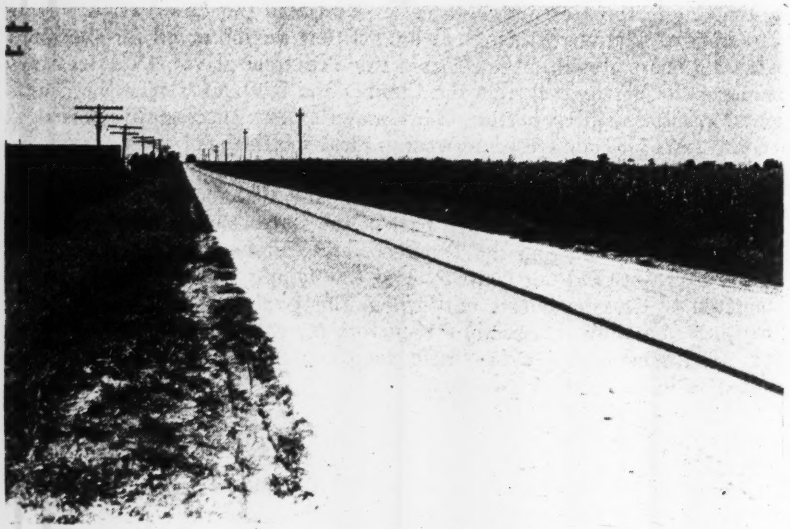

FIG. 2.—Bates Type Pavement.

Note markers at transverse cracks. This Project on the basis of the survey is the best that has been constructed by the Department of Highways. Length, 10.12 miles. Average transverse crack count, 49 per mile. Age, 6 yr. Crushed limestone, O.R.B.T. sand.

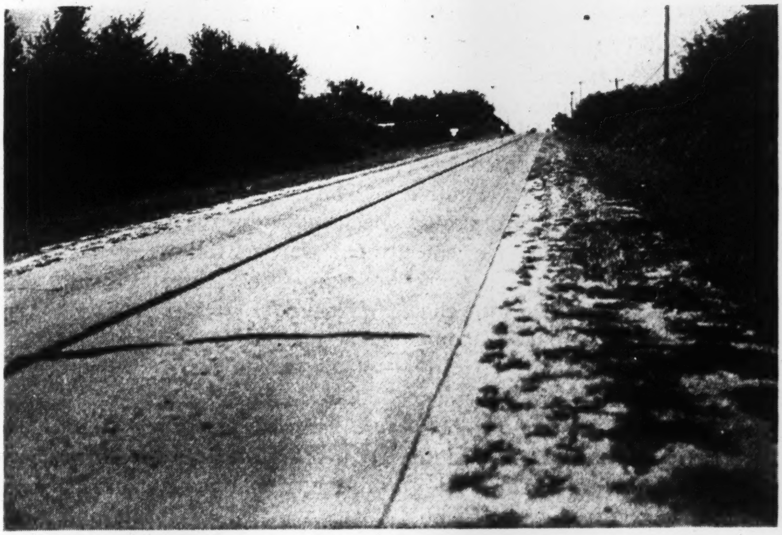

Fig. 3.—Bates Type Pavement in Excellent Condition.
Ohio River gravel, Ohio River sand. Age, 5½ yr.

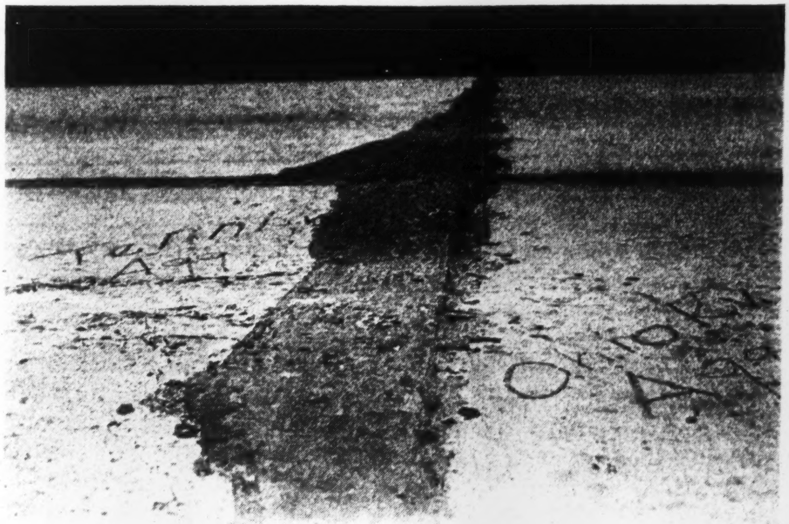

Fig. 4.—Construction Joint, Tennessee River Gravel on Left and Ohio River Gravel on Right.
Ohio River sand used in both concretes. Age, 8 yr.

reduce to a minimum, future concrete pavement failures.

Crushed materials used in pavement construction were limestone which is prevalent throughout the state, and eastern Kentucky sandstone. Uncrushed Ohio, Tennessee, and Cumberland River materials were used. The Ohio River material was obtained between Huntington, W. Va., and Paducah, Ky. Tennessee and Cumberland River materials were obtained in the western Kentucky area only.

An extensive condition survey of the existing pavement was started during 1937 and completed in 1938. A separate data sheet, divided into sections, was compiled for each paving project. The first section contained construction data and laboratory tests, and the second a tabulation of the condition survey. The condition survey consisted of a classification of all types of cracking and surface disintegration. Projects were divided into one-mile sections for convenience in surveying. Distances were measured with a Stewart-Warner Odometer calibrated in feet. Analyses of the completed data sheets constitute the basis of this paper.

In addition to the field survey, a series of laboratory tests were made on aggregates from representative sources, and on concrete beams in which these aggregates were incorporated.

SURVEY SUMMARY

Located in the western part of the state are 59 miles of concrete pavement which were classed as a major failure from the survey. The age of this pavement varies from 2 to 7 yr. Coarse aggregate used in all of the separate projects was obtained from the Tennessee and Cumberland Rivers in the western Kentucky area. Fine aggregate was obtained from the Cumberland River in western Kentucky and two distantly separated sources in the Ohio River. The first source of Ohio River material was approximately one mile below the mouth of the Tennessee River, the material hereinafter being referred to as O.R.B.T. sand. The second source was near Henderson, Ky., or approximately 100 miles upstream from the first.

The aggregate combinations that had been used in the unsatisfactory pavement were as follows:

Tennessee River gravel, O.R.B.T. sand (Fig. 1),
Tennessee River gravel, Ohio River sand, and
Cumberland River gravel, Cumberland River sand

In the same area are 145 miles of concrete pavement varying in age from 4 to $7\frac{1}{2}$ yr. which was classed as satisfactory. Aggregates used in this pavement were crushed limestone, Ohio River gravel, O.R.B.T. sand, and Ohio River sand.

Aggregate combinations that had been used in the satisfactory and durable pavement were as follows:

Crushed Limestone, O.R.B.T. sand (Fig. 2),
Crushed Limestone, Ohio River sand, and
Ohio River gravel, Ohio River sand (Fig. 3).

One project was constructed using only Ohio River sand in combination with gravel from the Tennessee and Ohio Rivers. The section in which Tennessee River gravel was incorporaed failed, while the section in which Ohio River gravel was used has a satisfactory service record (Fig. 4). Another project contained crushed limestone, Tennessee River gravel, and Ohio River gravel with the same sand and cement throughout. Failure resulted for the Tennessee River gravel section only.

By comparing pavements of different ages we find the following facts concerning disintegration. Transverse cracks form in the newly laid pavement, and after a certain period small map cracks form, radiating in all directions from the transverse crack which is the initial step in disintegration. After another period, progressive scaling sets in which is closely followed by general structural failure of the concrete. The condition outlined requires different periods with different aggregates; 1 to 2 yr. to show signs of disintegration, and 3 to 5 yr. to break down completely has been observed for chert gravel pavements. Ohio River gravel pavements were found to require 4 to 6 yr. to show map cracks, with only a very small amount of progressive scale developing at any age. Pavements constructed of crushed limestone show practically no sign of disintegration at any age. The only trouble found in limestone pavement is directly traceable to a high percentage of shale. The comparative durability and cracking of pavement constructed of various aggregates may be seen from Table I.

From the project survey sheets and the above, it is evident that Tennessee and Cumberland River gravel appeared as coarse aggregate in all major pavement failures occurring in western Kentucky, and that the fine aggregates did not contribute to this failure. Fine aggregate obtained from the Ohio River either above or below the mouth of the Tennessee River is a well-graded quartz material and has been used successfully with limestone or Ohio River gravel.

TABLE I.—THE EFFECT OF VARIOUS AGGREGATE COMBINATIONS ON DURABILITY AND CRACKING.

Miles Surveyed	Age, yr.	Coarse Aggregate	Fine Aggregate	Broken Area, sq. yd. per mile	Settled Area, sq. yd. per mile	Replaced Area, sq. yd. per mile	Remaining Miles	Transverse Crack Interval, ft.	Transverse Cracks Raveled and Spalled, per cent	Transverse Cracks Progressive Scale, per cent	Transverse Cracks with Map Cracks, per cent	Map Crack Area, sq. yd. per mile	Progressive Scaled Area, sq. yd. per mile	Checked Area, sq. yd. per mile	Longitudinal Crack, lin. ft. per mile	Internal Corner Breaks, per mile	External Corner Breaks, per mile	Blowups per mile
2.66	4	Tennessee River gravel	O.R.B.T. sand			14	2.66	24.8	2.5	16.6	11.1				6	2.6	1.5	0.8
28.77	5			115			28.52	25.1	8.0	16.9	7.6	120	3	132	111	9.7	2.9	3.4
15.97	7			35			15.92	35.6	2.8	28.7	6.2	92			57	7.6	1.5	12.4
23.21	7½			37	4	10	23.08	43.7	6.5	30.1	3.3	16	3	10	97	5.1	1.2	4.2
19.35	8			702			18.18	32.6	14.4	33.4	5.6	17	14		934	3.5	2.5	4.0
1.23	9					78	1.22	17.8	16.1	23.5	11.1	2023	182		98	1.6	2.5	12.3
5.10	7	Tennessee River gravel	Ohio River sand	1707		557	4.01	16.9	1.0	57.1	4.0	372	239		1029	2.2	1.2	4.7
8.91	8			53	22	17	8.83	32.3	14.6	48.4	5.1	137	61		37	4.2	2.2	2.5
9.86	4	Crushed limestone	O.R.B.T. sand				9.86	104.7	1.1						2	0.1		
22.15	5						22.15	101.5	19.5	2.0						1.1	0.1	
10.12	6						10.12	107.7	24.1						5	0.5		
5.89	7						5.89	110.0	6.1						6	1.0	0.7	
6.90	5½	Crushed limestone	Ohio River sand				6.90	98.0	31.4	20.7					4	0.9		
6.98	7						6.98	100.7	10.0						18	0.4	1.4	
2.50	7½						2.50	94.3	50.0	4.0					30	0.4		
2.56	4½	Ohio River gravel	Ohio River sand				1.64	22.3	5.1	3.6					73	1.8	0.6	
17.94	5					30	17.88	32.7	7.0	7.4	0.4				13	1.7	0.5	0.6
16.57	5½			3			16.57	39.1	8.2	3.2	0.3				23	2.4	0.4	0.8
25.06	7			3	4		25.05	43.0	15.6	23.6	0.2				58	1.0	0.3	2.0
14.65	8			36	3	3	14.59	36.9	11.0	20.0	1.8	3		65	42	1.1	0.4	1.2
18.29	10	Crushed sandstone	Crushed sandstone	27		156	17.92	49.5	13.2	83.6	1.0	1	100		37	2.2	0.7	0.4
7.43	11	Crushed sandstone	Ohio River sand	55	13	31	7.35	52.5	15.8	11.9					165	0.9	2.3	

All projects Bates type pavement, all projects on loam subsoils of western Kentucky except sandstone projects.

Crushed Sandstone Fine and Coarse Aggregate Results in Unsatisfactory Pavement:

An experiment was conducted to determine the desirability of eastern Kentucky sandstone as an aggregate for concrete pavement. The native sandstone used was composed of a silica sand with an iron oxide cement. Deval abrasion tests on this material gave an average value of 6 per cent, and toughness tests an average value of 8.

Projects were constructed using crushed sandstone for both fine and coarse aggregate. A total of 18.29 miles of pavement was constructed, 0.37 miles of which were classed as broken and replaced area. Natural transverse cracks averaged 107 per mile, 13 per cent of which was raveled or spalled, 84 per cent scaled, and 1 per cent showing initial disintegration. Progressive scaled area averaged 100 sq. yd. per mile. Blowups averaged 0.4 per mile. This pavement has a satisfactory natural transverse crack interval. However, the large amount of disintegration and failure occurring in 10-yr. pavement are factors that condemn the use of sandstone when used for both fine and coarse aggregate.

TABLE II.—PROPERTIES OF AGGREGATES FROM REPRESENTATIVE SOURCES.

All Tests are Prevailing A.S.T.M. Standards or Tentative Standards

	Cumberland River Gravel	Ohio River Gravel	Tennessee River Gravel	Limestone
Deval abrasion[a]	10.5	5.6	8.4	5.7
Los Angeles abrasion[b]		25.5	19.0	27.9
Soundness 5 alter. Sodium sulfate, per cent weight loss[b]		3.7		12.1
Soundness 5 alter. Sodium sulfate ledge rock method[a]	O.K.	O.K.	O.K.	O.K.

[a] Average of tests 1928 to 1938.
[b] Average of 30 tests on each aggregate.

Crushed Sandstone Coarse Aggregate and Ohio River Sand Fine Aggregate Results in Satisfactory Pavement:

The total mileage constructed using crushed sandstone as coarse aggregate and Ohio River sand as fine aggregate was 7.94; 0.08 miles of which were classed as broken, settled, and replaced area. An average of 81 natural transverse cracks per mile occurred in this pavement, 35 per cent of which was raveled or spalled, and 24 per cent scaled. No progressive scaled area or blowups occurred. The small amount of disintegration and failure occurring in 11-yr. pavement in which crushed sandstone and Ohio River sand were incorporated, recommends this combination for future construction.

TABLE III.—ANALYSIS OF AGGREGATES FROM REPRESENTATIVE SOURCES.

NOTE.—Analysis per cent by weight. The sandstones have iron oxide, silica, calcium, carbonate, or clay cementing material.

TENNESSEE RIVER GRAVEL MINERALOGICAL	
Sound chert	64.7
Weathered chert	28.8
Quartz	1.4
Quartzite	3.1
Sandstone	2.0

OHIO RIVER GRAVEL MINERALOGICAL	
Granite	34.8
Quartzite	17.9
Sound chert	12.1
Basalt-Diorite	11.8
Sandstone	11.8
Ferromagnesiums	6.5
Quartz	2.8
Limestone	2.3

CUMBERLAND RIVER GRAVEL MINERALOGICAL	
Sound chert	89.5
Weathered chert	1.9
Quartz	2.7
Quartzite	3.7
Sandstone	2.2

LIMESTONE QUANTITATIVE	
$CaCO_3$	91.40
$MgCO_3$	5.90
SiO_2	1.68
R_2O_3	0.88

LABORATORY TESTS

Changing comparison from the service record of pavements to laboratory abrasive, soundness, and strength tests we find chert gravel to be equal to limestone or Ohio River gravel.

Gravel from the Tennessee and Cumberland Rivers has passed all standard laboratory tests for abrasion and soundness. The average of tests made on various materials during the past 10 yr. are shown in Table II.

Strength tests on chert gravel concrete field specimens, with a water cement ratio of 0.70, show values between 600 and 700 psi. for 28-day flexural strength, and 3000 to 4000 psi. for 28-day compressive strength. Similar tests on specimens in which Ohio River gravel or crushed limestone are incorporated show results practically the same.

TABLE IV.—COMPARATIVE SPECIFIC GRAVITY AND ABSORPTION TESTS.

Average of 1937–1938 Tests.

Source of Material	Bulk Specific Gravity	Absorption, 3 hr. Boiling Water, per cent
Ohio River, Carrollton, Ky.	2.68	0.7
Ohio River, Louisville, Ky.	2.65	0.8
Ohio River, below mouth Green River	2.54	2.4
Tennessee River, 20 miles upstream from mouth	2.34	5.3
Tennessee River, 5 miles upstream from mouth	2.32	5.5
Cumberland River, Clarksville, Tenn.	2.44	3.5
Limestone, Lexington, Ky.	2.70	0.3

AGGREGATE RESEARCH PROGRAM

For the purpose of the coarse aggregate research program laboratory tests were made on representative samples of crushed limestone, Ohio, Tennessee, and Cumberland River gravel. Mineralogical analyses of these aggregates are shown in Table III.

Approximately 90 per cent of Tennessee and Cumberland River gravel is chert. Geological definitions of chert vary; however the most widely used defines it as an impure flint and jasper with crystals of pyrite and other foreign material. The color varies from white to gray such as found in the Golden Pond area of western Kentucky. Chert gravel obtained in the western Kentucky area is extremely porous, highly absorptive, and has a low specific gravity. Comparative bulk specific gravity tests, A.S.T.M. Tentative Method C 127 – 36 T,[2] section 6, and 3-hr. boiling water absorption tests, A.S.T.M. Standard Method C 95 – 36,[3] are shown in Table IV.

TABLE V.—PROPERTIES OF AGGREGATES USED IN FREEZING-AND-THAWING TESTS OF CONCRETE BEAMS.

Material	Bulk Specific Gravity	Absorption, 3 hr. Boiling Water, per cent	Los Angeles Abrasion (A.S.T.M. C131 – 38 T)	Deval Abrasion (A.S.T.M.; Stone D 2 – 33, Gravel D 289 – 37 T)	Soundness 5 Alter. Sodium Sulfate (A.S.T.M. C 89 – 37 T Ledge Rock Method)
Tennessee River Gravel	2.33	5.4	19.2	7.6	O.K.
Cumberland River Gravel	2.45	3.8	....	9.8	O.K.
Ohio River Gravel	2.67	0.6	20.1	5.4	O.K.
Crushed Limestone	2.70	0.3	26.8	6.0	O.K.

In addition to the tests described above, the behavior of the four types of coarse aggregate when incorporated in concrete beams and subjected to freezing and thawing was investigated. Properties of the aggregates used in the tests are shown in Table V.

One shipment of portland cement meeting the usual requirements was used in all beams. Fine aggregate used throughout the tests was obtained from the Ohio River below the mouth of the Tennessee River, and had the following properties:

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[2] Tentative Method of Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 – 36 T), *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 805 (1936); also 1938 Book of A.S.T.M. Tentative Standards, p. 651.

[3] Standard Method of Test for Absorption by Aggregates for Concrete (Laboratory Determinations) (C 95 – 36), 1936 Book of A.S.T.M. Standards, Part II, p. 330.

Bulk specific gravity	2.62
Sieve Analysis, per cent:	
Passing ⅜ in. sieve	100.0
Passing No. 4 sieve	99.9
Passing No. 16 sieve	66.0
Passing No. 50 sieve	10.4
Passing No. 100 sieve	3.0

The concrete used in the beams was specified as follows:

Cement factor: 1.5 bbl. per cu. yd. concrete.
Water-cement ratio: 5.75 gal. per sack, correction made for moisture content of aggregate.
Sand in combined fine and coarse aggregates, per cent by weight: gravel mix, 35; limestone mix, 38.
Slump, in.: 1 to 2½
Maximum size coarse aggregate, in.: 2½
Molding test specimens: Rodded 50 times per square foot of area A.S.T.M. Method C 78 - 38.[4]
Curing: 7 days burlap and water at 70 F., 7 days in air.
Size: 6 by 6 by 42-in. beams.
Number of beams: 8 from each type aggregate.

The concrete beams were subjected to freezing and thawing after a 14-day curing period, because this period approximates certain field conditions. The beams were immersed in water, and subjected to a freezing period of 16 hr. at a temperature between -5 F. and -10 F. After the freezing period the beams were thawed in water at 70 F. for a period of 8 hr. Flexural tests were made on the concrete beams at 14 and 28 days, and also after 40 cycles of freezing and thawing. Comparative results of these tests are shown in Table VI.

TABLE VI.—SHOWING REDUCTION IN FLEXURAL STRENGTH OF CONCRETE AFTER 40 CYCLES OF FREEZING AND THAWING.

Fine Aggregate	Coarse Aggregate	Modulus of Rupture, 14 days, psi.[a]	Modulus of Rupture, 28 days, psi.[a]	Absorption of Concrete, per cent	Modulus of Rupture, psi., 14-day beams After 40 cycles Freezing and Thawing[b]	Absorption of Concrete After 40 cycles Freezing and Thawing, per cent	Reduction in Modulus of Rupture After 40 cycles Freezing and Thawing, per cent
O.R.B.T. sand	Tennessee River gravel	582	637	7.6	0	8.7	100.0
	Cumberland River gravel	693	710	4.6	431	7.8	37.8
	Ohio River gravel	763	810	3.5	610	4.2	20.0
	Limestone	795	860	2.9	745	3.8	6.3

[a] Represents average of 6 tests on each aggregate.
[b] Represents average of 4 tests on each aggregate.

Concrete pavement constructed of chert gravel obtained in western Kentucky shows signs of disintegration after exposure to actual weathering conditions for a period as short as one year. Beams manufactured from this aggregate show a decrease in flexural strength from 35 to 100 per cent when subjected to 40 cycles of freezing and thawing in the presence of water. The void space in aggregate particles and concrete has long been recognized as an important factor in the durability of concrete. Highly absorptive concrete is subject to rapid disintegration and failure when exposed to weathering conditions. Chert gravel concrete has an absorption approximately twice that of the same concrete in which crushed limestone or Ohio River gravel is incorporated. Varying the moisture content and temperature of chert gravel concrete produces large volume changes, due to the confined moisture and the expansive nature of the aggregate. The bond is broken permitting increased absorption and volume changes; thus general structural failure results.

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[4] Standard Method of Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third Point Loading) (C 78 - 38), 1938 Supplement to Book of A S.T.M. Standards, p. 119.

CONCLUSIONS

Based on the investigation outlined, the following conclusions have been drawn. The influencing factors are necessarily those found in our state.

1. The failure of concrete pavement throughout the western part of the State was due to the use of chert gravel obtained from the Tennessee and Cumberland Rivers in western Kentucky.

2. With the present methods of pavement construction, this chert gravel will not produce durable pavement.

3. Chert gravel found to produce unsatisfactory pavement in Kentucky may be eliminated by two specifications:

(*a*) Coarse aggregate shall not show an absorption greater than 3 per cent when subjected to A.S.T.M. Standard Test C 95 – 36.

(*b*) Concrete in which any aggregate is incorporated shall not show a reduction in flexural strength greater than 30 per cent when subjected to 40 cycles of freezing and thawing in the presence of water.

4. Tennessee or Cumberland River sand will produce durable pavement when used with Ohio River gravel or crushed limestone.

5. The use of sandstone as both fine and coarse aggregate resulted in unsatisfactory pavement.

6. The use of sandstone and Ohio River sand as aggregates resulted in satisfactory pavement.

DISCUSSION

Mr. Stanton Walker.[1]—The paper by Messrs. Cantrill and Campbell is a valuable contribution to the literature of concrete. It presents what to my personal knowledge is an accurate picture of a most serious problem which confronts concrete engineers in some sections of the country. While the authors have emphasized that the conditions which they describe apply only to certain chert gravels used in certain sections of Kentucky, I wish to emphasize that fact further by pointing out that there are good chert gravels and bad chert gravels just as there are good and bad aggregates of other mineral composition.

There is no ignoring the fact that certain cherts perform poorly and that certain chert gravels have given a bad or "spotty" service record. However, engineers in their enthusiasm to safeguard the quality of materials must not overlook the fact that long and satisfactory service records have been experienced with many, probably most, of the chert gravels produced by established plants and with most of the gravels not predominating in chert but containing substantial quantities of it. It should be understood that cherts may be good and they may be bad, and that it is only excessive quantities of bad chert that need to be guarded against.

Chert is a term that is loosely used by most engineers and many geologists, and there are a number of theories concerning its origin. As most commonly known, it is associated with chalk and limestone deposits, and is often referred to as an impure flint. However, the application of the term has been broadened, particularly among engineers, so that the tendency is to include almost any rock composed of microcrystalline or cryptocrystalline silica. Cherts, under any such broad definition, vary greatly in physical characteristics. They range from hard, dense, flint-like particles to lightweight porous particles. They are of a variety of colors, including white, gray, brown and others, the color coming from impurities present in small quantities. Basically, microcrystalline silicas are sound and durable minerals, but porous and impure particles may disintegrate under freezing and thawing in a saturated condition or change in volume sufficiently to disrupt the concrete.

The Tennessee River is an example of a source of gravels which are predominantly chert. Those gravels vary widely in physical characteristics, and a large proportion of them have provided excellent service records in concrete. Comprehensive information on the variations in physical characteristics of gravel from the Tennessee River is given in a paper by Spain and Rose[2] which covers a study of Tennessee River gravel from a number of widely separated points between Chattanooga and the mouth of the river. It shows a wide range in the proportions of sound and weathered chert with the proportion of weathered chert increasing, in general, as the mouth of the river is approached. For example, the ratio of sound to weathered chert was found to be only about 2 to 1 some 25 miles above the river mouth, and about 7 to 1 some 220 miles from the mouth.

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[1] Director of Engineering, National Sand and Gravel Assn., Washington, D. C.

[2] E. L. Spain, Jr., and N. A. Rose, "Geological Study of Gravel Concrete Aggregate of the Tennessee River," *Technical Publication No. 840*, October, 1937, Am. Inst. Mining and Metallurgical Engrs.

There is a considerable amount of other information to indicate that all chert gravels cannot be classed in one category any more than all limestones, for example, can be placed in a single class. What is needed for that material, as for others, is a method for distinguishing between sound and unsound materials. Perhaps the absorption test, to which the authors refer, is the answer. Certainly different chert gravels vary widely in absorption and also in specific gravity. Tests carried out in the laboratory of the National Sand and Gravel Association Research Foundation at the

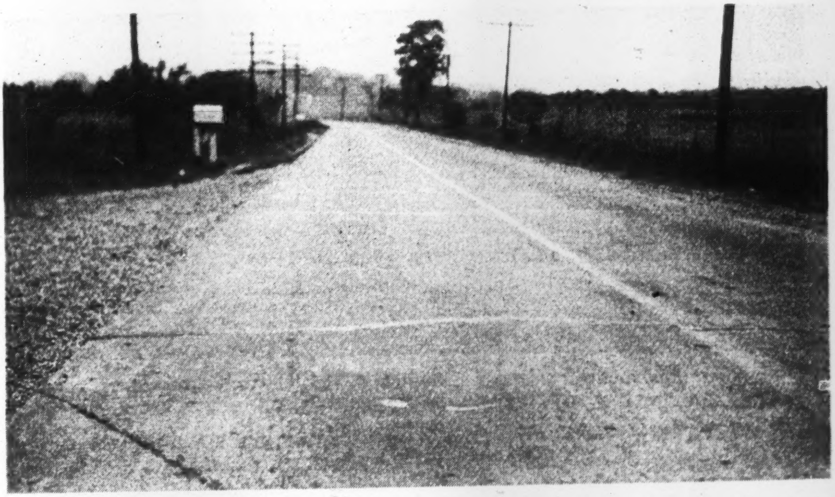

FIG. 1.—Concrete Pavement in Missouri, Built in 1929. Coarse aggregate was chert gravel.

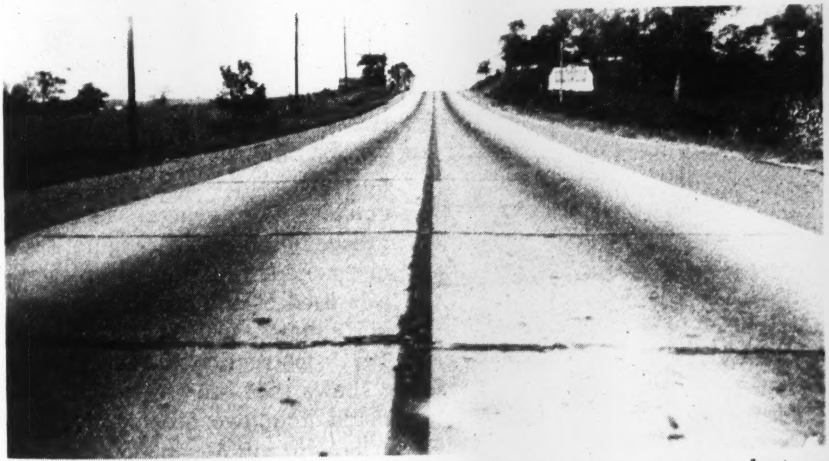

FIG. 2.—Concrete Pavement in Tennessee, Built in 1928. Coarse aggregate was chert gravel.

University of Maryland have shown bulk specific gravities of chert gravels from different sources to range from about 2.5 to 2.3 or lower, and selected particles to have specific gravities as low as about 2.0. Absorptions have shown comparable ranges and, in general, it would appear that unsatisfactory service records are most prevalent where the gravels of low specific gravity and high absorption were used.

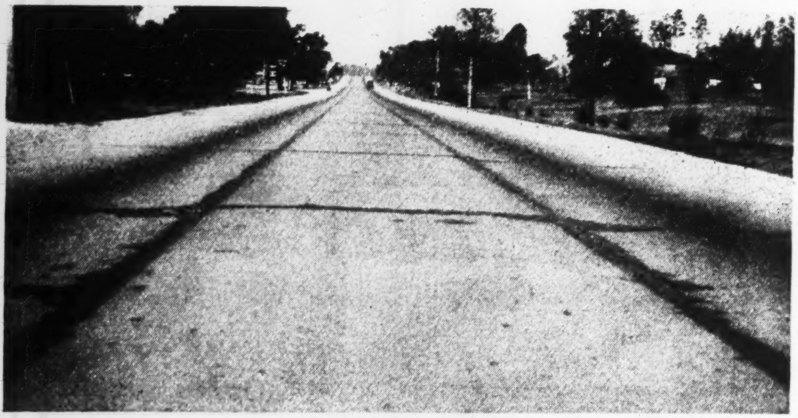

FIG. 3.—Concrete Pavement in Tennessee, Built in 1931. Coarse aggregate was chert gravel.

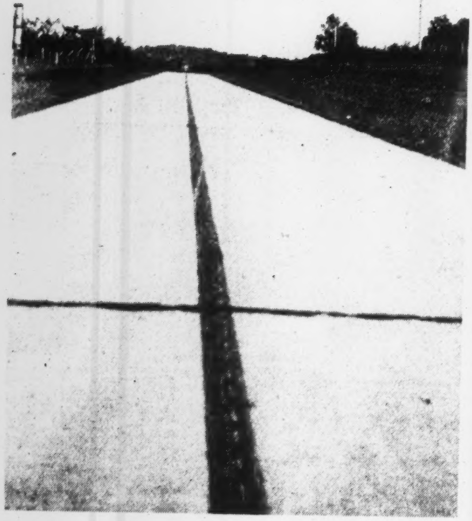

FIG. 4.—Concrete Pavement in Tennessee, Built in 1934. Concrete made with two different chert gravels shown in view.

As stated previously, many chert gravels have long and honorable service records. The accompanying Fig. 1 is a view of Route 30, Section 78, St. Louis County, Mo., built in 1929 with chert gravel from the Meramec River as a coarse aggregate. No signs of disintegration are evident other than the normal transverse and longitudinal cracking. In general, the road is in excellent condition. Figure 2 is a view of a concrete road in which chert gravel was used as the coarse aggregate, built in Tennessee in 1928; Fig. 3 shows some 1931 construction in Tennessee; and Fig. 4 shows 1934 construction with concrete made from two different chert gravels. I have in my files photographs showing conditions similar to those cited by the authors, but I have selected these pictures to illustrate that good chert gravel may be used to make good concrete.

It will be recognized that there are factors other than the quality of the coarse aggregate affecting the quality of the concrete. Even in those areas where chert gravels with a bad to spotty service record have been used, we find sections of roads which are in perfect condition made from the same material as those sections which have disintegrated. There is some reason for those differences, even though we cannot identify them. Something was done to the concrete that went into the perfect sections that was not done to that going into the disintegrated sections. We should find out what that "something" is.

THE CHAIRMAN (*Mr. A. T. Goldbeck*[3]).—There is one point that was very interesting to me in the paper, namely, the comparison between laboratory tests and service behavior. For instance, in the table giving test results, the loss in the sodium sulfate test for the limestone was something over 12 per cent, and there are many specifications that do not permit as high a loss as 12 per cent. In other words, the limestone might be considered as unsound, and yet in service it gave excellent results. On the other hand, the sodium sulfate test, when performed on the chert gravel, gave a very low percentage of loss, and yet the chert gravel concrete roads did not give good service results. Here are two very clear-cut cases where the sodium sulfate test has not given a reliable indication of the soundness of the material.

MR. W. F. KELLERMANN.[4]—I believe it would be of interest if the authors will give some of the details of the test procedure followed in making the freezing-and-thawing test. I should be particularly interested in knowing the thawing temperature, the minimum temperature reached, and the length of time required for freezing.

MR. CURTIS CANTRILL.[5]—The concrete beams were subjected to freezing and thawing after a 14-day curing period, because this period approximates certain field conditions. The beams were placed in water-filled containers, and subjected to a freezing period of 16 hr. at a temperature between −5 F. and −10 F. No thermocouples were placed in the specimens. Temperature during the freezing period was determined by thermometers suspended in the refrigerator. After the freezing period the beams were thawed in water at 70 F. for a period of 8 hr.

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[3] Engineering Director, National Crushed Stone Assn., Inc., Washington, D. C.

[4] Associate Materials Engineer, Public Roads Administration, Washington, D. C.

[5] Senior Materials Engineer, Kentucky Department of Highways, Frankfort, Ky.

DEGRADATION OF AGGREGATES UNDER ROAD ROLLERS

By Tilton E. Shelburne[1]

Synopsis

This paper reports data on the degradation produced by 5-ton and 10-ton rollers in compacting typical uncoated surface treatment aggregates both on a bituminous mat and on a concrete base. Several gradings of six limestones, four crushed and four uncrushed gravels, and one blast-furnace slag were tested. Data are also reported showing the relationship between degradation of aggregates under rollers and losses obtained in the Los Angeles tests.

The rollers showed a tendency to break down the large particles into smaller ones without producing much dust, while in the Los Angeles rattler breakage was noticeable on all sizes of particles, producing a greater quantity of dust. The rating of the aggregates by the roller tests was approximately the same as by the Los Angeles tests. At 100 revolutions in the rattler, the abrasion losses were of the same order of magnitude as the losses produced by seven round trips under the rear wheels of the 10-ton roller on the rigid base; however, at 100 revolutions the amount of degradation ranged from five to ten times greater. The resultant cumulative grading of the aggregates after 500 revolutions in the rattler represented an approximation of Fuller's curve.

An average of all tests showed that more than twice as much degradation was produced upon the concrete base as upon the bituminous mat. For all the trips on the rigid base, the average work done by the front and rear rollers of the 10-ton machine was 40 and 60 per cent, respectively, and 20 and 80 per cent for the 5-ton roller. Tests on crushed and uncrushed gravels indicated that particle shape influences the amount of degradation, the round uncrushed particles being more resistant to the crushing action of the roller. These tests indicated also that chipping aggregates exerted a protective action against degradation when added to coarser covering aggregates and suggested the possibility that a dense graded aggregate might be relatively free from degradation. From these studies it appears that both during construction and later under traffic, aggregates follow a fixed manner of degrading. The degree of degradation depends upon the amount of work done upon them.

A cooperative research project between the State Highway Commission of Indiana and Purdue University was established in June, 1936. The immediate problem of importance to the Highway Commission was an investigation of bituminous surface treatments. Surveys were made, and numerous samples were collected throughout the state from bituminous surface treatments constructed in 1935, 1936 and 1937. From field observations and laboratory analyses of these samples, it was found that the gradation of the aggregates was in no case the same as that originally used in construction. The greater part of the change in grading apparently resulted from manipulation and rolling during construction; a lesser amount resulted from traffic.

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[1] Research Engineer, Joint Highway Research Project, Purdue University, Lafayette, Ind.

As a means of determining the amount of degradation produced by road rollers, a series of tests was devised in which a number of typical surface treatment aggregates were rolled on a flexible and on a rigid base under 5-ton and 10-ton rollers. Since several variables were anticipated in the use of bituminous coated aggregates, only dry, uncoated aggregates were used in this investigation. Additional tests covering bituminous-coated aggregates have been outlined for a continuation of this study.

Goldbeck,[2] Rothgery,[3] and Tremper[4] found variations in the resistance of different types of aggregates to crushing under laboratory rollers. In some of their tests certain variables were encountered which may not be comparable to actual field conditions, such as pronounced edge effect of narrow rollers, large angle of nip, or twisting action induced by small diameter circular tracts. Macnaughton[5] also found, in compacting laboratory specimens of bituminous mixtures both by direct compression and by means of a high-frequency power tamper to reproduce field densities, that a large amount of crushing of aggregate particles took place. In order to eliminate these objections, the aggregates were compacted with road rollers under actual field conditions. A comparison was made between the amount of degradation produced by road rollers and that produced by the Los Angeles abrasion machine.[6, 7, 8, 9, 10, 11]

DESCRIPTION OF EQUIPMENT

Two types of bases were constructed and cured one month before using. The flexible base, 9 ft. wide by 50 ft. long, consisted of a $2\frac{1}{2}$-in. bituminous mat on 9 in. of compacted pit-run gravel. The rigid base, 8 ft. wide by 50 ft. long, was a 6-in. concrete slab laid on 6 in. of compacted pit-run gravel.

The 10-ton roller (used in series I to IV) was an Austin-Western Autocrat three-wheel machine. The front roller was 45 in. wide, had an outside diameter of 43 in., and was rated by the manufacturer as weighing 170 lb. per lineal inch; the rear rollers were 20 in. wide with an outside diameter of 67 in., and rated at 310 lb. per lineal inch. The 5-ton roller (series V) was a Huber three-wheel machine. The front roller was 37 in. wide with an outside diameter of 34 in., and rated by the manufacturer as weighing 94 lb. per lineal inch; the rear rollers were 18 in. wide with an outside diameter of $51\frac{1}{2}$ in. and rated as weighing 244 lb. per lineal inch.

The Los Angeles abrasion tests were run by the Bureau of Materials and Tests of the State Highway Commission of Indiana in accordance with the requirements of the A.S.T.M. Tentative Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles

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[2] A. T. Goldbeck, J. E. Gray, L. L. Ludlow, Jr., "A Laboratory Service Test for Pavement Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 608 (1934).

[3] L. J. Rothgery, "Los Angeles Rattler Test," *Rock Products*, Vol. 39, No. 12, December, 1936, p. 42.

[4] Bailey Tremper, "A Test for Resistance of Stone to Breakage During Rolling," *Bulletin No. 17*, State of Washington, Department of Highways, December, 1935.

[5] M. F. Macnaughton, "Physical Changes in Aggregates in Bituminous Mixtures Under Compaction," *Proceedings*, Assn. Asphalt Paving Technologists, Vol. 8, January, 1937, p. 7.

[6] C. L. McKesson, "Selection of Rock and Gravel for Highway Construction," *California Highways*, Vol. 3, No. 4, April 1, 1926, pp. 6–11.

[7] Unpublished report of California Division of Highways, June 13, 1930.

[8] A. H. Gawith, "The Los Angeles Abrasion Tests," *Main Roads*, Vol. 8, No. 2, February, 1937, p. 54.

[9] D. O. Woolf and D. G. Runner, "The Los Angeles Abrasion Machine for Determining the Quality of Coarse Aggregate," *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part II, p. 511 (1935).

[10] W. H. Wood, "Significance of the Los Angeles Abrasion Tests as the Measure of the Service Value of Coarse Aggregates," Texas State Highway Department, Austin, Texas, December, 1938.

[11] D. O. Woolf, "Results of Cooperative Tests Using the Los Angeles Abrasion Machine," *Proceedings*, Highway Research Board, Vol. 16, pp. 174–180 (1936).

Machine (C 131 – 37 T).[12] In addition to determining the percentage of wear, a complete sieve analysis was made of the samples after 100 and 500 revolutions using the following standard square-mesh sieves: $\frac{1}{2}$-in., $\frac{3}{8}$-in., $\frac{1}{4}$-in., Nos. 4, 8, 12, 16, 30, 50, 100, and 200.

TABLE I.—IDENTIFICATION AND DESCRIPTION OF THE AGGREGATES TESTED

Identification		Description			
A-1		Dolomitic limestone			
A-2		Mitchell limestone (calcareous)			
A-3		Kokomo dolomite, containing naturally impregnated oil			
A-4		Mitchell limestone (calcareous)			
A-5		Niagaran dolomite (very porous)			
A-6		Mitchell limestone (calcareous)			
		Lithological Composition, per cent by weight			
		Soft Particles	Calcareous	Traps and Granites	Siliceous
B-1	Glacial pit gravel (100 per cent crushed)	0.0	57.6	25.6	16.8
B-1.1	Glacial pit gravel (93.2 per cent uncrushed)	0.1	73.9	11.9	14.1
B-2	Glacial pit gravel (100 per cent crushed)	0.0	47.4	18.6	34.0
B-2.1	Glacial pit gravel (uncrushed)	0.0	50.3	17.4	32.3
B-3	Ohio River Gravel (100 per cent crushed)	0.0	9.0	29.3	61.7
B-3.1	Ohio River Gravel (uncrushed)	0.3	17.9	36.6	45.2
B-4	Glacial pit gravel (100 per cent crushed)	0.1	60.7	7.3	31.9
B-4.1	Glacial pit gravel (50 per cent uncrushed)	0.3	56.0	15.0	28.7
C-1	Blast furnace slag—83 lb. per cu. ft.				

TABLE II.—SPECIFICATION LIMITS FOR AGGREGATE SIZES.

	Total Retained on Sieves Having Square Openings, per cent				
	¾-in. Sieve	½-in. Sieve	⅜-in. Sieve	No. 4 Sieve	No. 8 Sieve
Los Angeles "B" grading	0	50	50		
Size 8F	0	40 to 70		95 to 100	99 to 100
Size 11		0	5 to 25	70 to 95	95 to 100

TABLE III.—TEST PROCEDURE.

Series	Variable	Roller			Aggregate
		Weight, tons	Number Round Trips	Average Speed, m.p.h.	
I	Number of trips	10	1 to 8	2.38	A-1 and B-1
II	Type and characteristic of aggregate	10	7	3.59	A-1, A-2, A-3, A-4, A-5, A-6; B-1, B-2, B-3, B-4, and C-1
III	Gradation of aggregate	10	7	2.45	A-2 and B-2
IV	Comparison of crushed and uncrushed gravel	10	7	2.21	B-1, B-2, B-3, B-4, B-1.1, B-2.1, B-3.1, and B-4.1
V	Number of trips	5	1 to 9	1.64	A-1 and B-1

Aggregates:

Typical surface treatment aggregates were collected from different sources throughout Indiana. These were graded to sizes 8F ($\frac{3}{4}$ in. to No. 4) and 11 ($\frac{1}{2}$ in. to No. 8) of the State Highway Commission's 1936 specification requirements. With one exception (A-5), the materials used are rated as class A by the Commission. Table I furnishes descriptions of the aggregates; the sizes used are shown in Table II.

ROLLER TEST PROCEDURE

Table III shows an outline of the tests. Both bases were divided and marked into 3-ft. sections of length (Fig. 1). In each series the base was covered by hand with 40 lb. per sq. yd. of aggregate. Extreme care was used to obtain uniformity of surface texture and base coverage. Adjacent sections consisted of different types of aggregates; the same arrangement of materials was used on both bases. The aggregates were in a dry condition at the time of rolling.

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[12] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 801 (1937); also 1937 Book of A.S.T.M. Tentative Standards, p. 590.

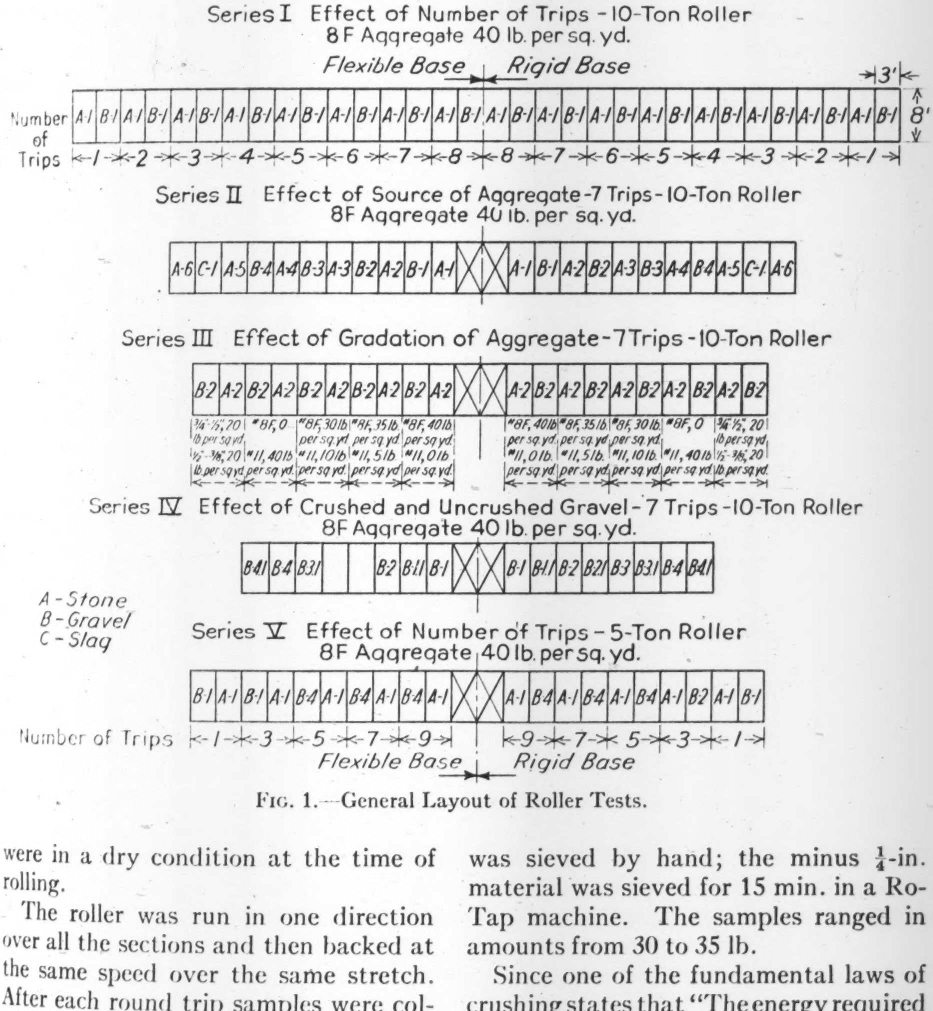
Series I Effect of Number of Trips - 10-Ton Roller
8 F Aggregate 40 lb. per sq. yd.
Flexible Base
Rigid Base
3'
8'
Number of Trips
A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1 A-1 B-1
1 2 3 4 5 6 7 8 8 7 6 5 4 3 2 1
Series II Effect of Source of Aggregate - 7 Trips - 10-Ton Roller
8F Aggregate 40 lb. per sq. yd.
A-6 C-1 A-5 B-4 A-4 B-3 A-3 B-2 A-2 B-1 A-1 A-1 B-1 A-2 B-2 A-3 B-3 A-4 B-4 A-5 C-1 A-6
Series III Effect of Gradation of Aggregate - 7 Trips - 10-Ton Roller
B-2 A-2 B-2 A-2 B-2 A-2 B-2 A-2 B-2 A-2 A-2 B-2 A-2 B-2 A-2 B-2 A-2 B-2 A-2 B-2
3/4"-1/2", 20 lb per sq yd, 1/2"-3/8", 20 lb. per sq yd
#8F, 0 #11, 40 lb per sq. yd.
#8F, 30 lb per sq. yd #11, 10 lb per sq yd.
#8F, 35 lb. per sq. yd. #11, 5 lb. per sq. yd
#8F, 40 lb. per sq yd. #11, 0 lb per sq. yd.
#8F, 40 lb per sq. yd. #11, 0 lb. per sq. yd.
#8F, 35 lb. per sq. yd #11, 5 lb. per sq. yd.
#8F, 30 lb. per sq. yd. #11, 10 lb. per sq. yd.
#8F, 0 #11, 40 lb per sq. yd.
3/4"-1/2", 20 lb per sq yd 1/2"-3/8", 20 lb. per sq. yd.
Series IV Effect of Crushed and Uncrushed Gravel - 7 Trips - 10-Ton Roller
8F Aggregate 40 lb. per sq. yd.
B-4.1 B-4 B-3.1 B-2 B-1.1 B-1 B-1 B-1.1 B-2 B-2.1 B-3 B-3.1 B-4 B-4.1
A - Stone
B - Gravel
C - Slag
Series V Effect of Number of Trips - 5-Ton Roller
8F Aggregate 40 lb. per sq. yd.
B-1 A-1 B-1 A-1 B-4 A-1 B-4 A-1 B-4 A-1 A-1 B-4 A-1 B-4 A-1 B-4 A-1 B-2 A-1 B-1
Number of Trips
1 3 5 7 9 9 7 5 3 1
Flexible Base
Rigid Base

FIG. 1.—General Layout of Roller Tests.

The roller was run in one direction over all the sections and then backed at the same speed over the same stretch. After each round trip samples were collected from the end sections and stored until sieve analyses could be made. One sample acted upon by the rear rollers was collected and also one that had been rolled only by the front rollers. Overlap material, compacted by both rollers, was discarded. In each case, except in series I, a sample of the edge material, not touched by the rollers, was collected for each 3-ft. section and used in comparison with the gradation after rolling. Complete sieve analyses were made of each sample. The plus $\frac{1}{4}$-in. material was sieved by hand; the minus $\frac{1}{4}$-in. material was sieved for 15 min. in a Ro-Tap machine. The samples ranged in amounts from 30 to 35 lb.

Since one of the fundamental laws of crushing states that "The energy required for crushing is proportional to the new surface formed"[13] or "the energy required

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[13] P. Ritter von Rittinger, "Lehrbuch der Aufbereitungskunde," p. 19, Berlin (1867).

TABLE IV.—SURFACE AREA FACTORS.

Passing	Retained on	Factor
¾-in. Sieve	⅜-in. Sieve	2.2
⅜-in. Sieve	No. 4 Sieve	4.0
No. 4 Sieve	No. 8 Sieve	6.3
No. 8 Sieve	No. 16 Sieve	12.7
No. 16 Sieve	No. 50 Sieve	30.0
No. 50 Sieve	No. 100 Sieve	100.0
No. 100 Sieve	No. 200 Sieve	205.0
No. 200 Sieve	Pan	615.0

NOTE.—Assumed specific gravity = 2.65. To correct multiply factors by $\frac{2.65}{\text{sp. gr.}}$.

is proportional to the reduction in diameter,"[14] measurements of the degradation produced by roller action were made on the basis of the surface area increases determined by sieve analyses. The factors used for computing surface areas are given in Table IV and are for an assumed specific gravity of 2.65. These values are similar to those used by Ebberts and Johnstone[15] in which all the material passing the No. 4 sieve was assumed to be spherical, while everything retained on the No. 4 was assumed as one-third cubes and two-thirds parallelepipeds with sides of 1:2:4 proportions. This procedure was previously discussed by Edwards.[16]

ROLLER TEST RESULTS

Effect of the Number of Trips of a 10-ton Roller (Series I):

A limestone (A-1) and a crushed gravel (B-1), both size 8F were subjected to from one to eight round trips of the 10-ton roller. Table V shows a summary of the results. The results obtained on the rigid base were more regular than those on the flexible one. The amount of degradation produced by the rollers on the flexible base reached a maximum after from two to five round trips. For eight round trips on the flexible base, the degradation produced

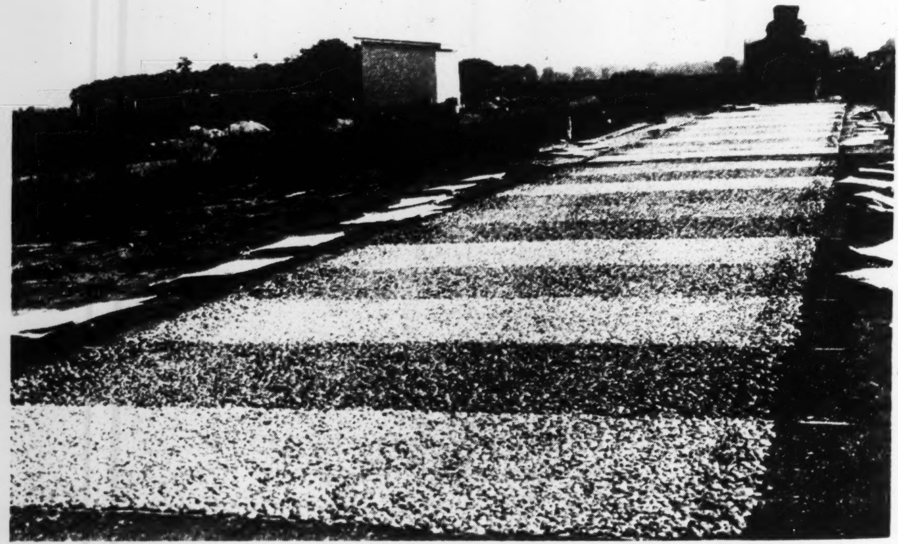

FIG. 2.—Series II—After Seven Round Trips of 10-ton Roller. The rigid base is in the background.

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[14] Robert H. Richards and Charles E. Locke, "A Text Book of Ore Dressing," Second Edition, New York City (1925).

[15] Alfred R. Ebberts and Hugh Johnstone, "Bituminous Pavements, An Introduction to the Art," Pittsburgh, Pa. (1936).

[16] L. N. Edwards, "Proportioning the Materials of Mortars and Concretes by Surface Areas of Aggregates," *Proceedings*, Am. Soc. Testing Mats., Vol. XVIII, Part II, p. 235 (1918).

TABLE V.—SERIES I—THE EFFECT OF THE NUMBER OF TRIPS OF A 10-TON ROLLER ON TYPICAL SIZE 8F AGGREGATES.

		On Flexible Base							On Rigid Base						
		Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent		Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent	
		Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers
A-1 Limestone 40 lb. per sq. yd.	Original	305.7	305.7	....	....	....	....	....	305.7	305.7	....	....	....	....	....
	1 Trip	373.6	417.9	67.9	112.2	180.1	22.2	36.7	473.8	566.8	168.1	261.1	429.3	55.0	85.4
	2 Trips	328.1	416.1	22.4	110.4	132.8	7.3	36.1	612.8	753.8	307.1	448.1	755.2	100.5	146.6
	3 Trips	402.0	493.0	96.3	187.3	283.6	31.5	61.3	493.4	802.7	187.7	497.0	684.7	61.4	162.6
	4 Trips	436.2	494.1	130.5	188.4	318.9	42.7	61.6	607.7	789.3	302.0	483.6	785.6	98.8	158.2
	5 Trips	434.2	509.7	128.5	204.0	332.5	42.0	66.7	589.2	1121.7	283.5	816.0	1099.5	92.7	266.9
	6 Trips	418.4	505.5	112.7	199.8	312.5	36.9	65.4	763.0	1056.3	457.3	750.6	1207.9	149.6	245.5
	7 Trips	434.1	492.6	128.4	186.9	315.3	42.0	61.1	946.1	1121.3	640.4	815.6	1456.0	209.5	266.8
	8 Trips	436.8	504.5	131.1	198.8	329.9	42.9	65.0	1126.5	1148.8	820.8	843.1	1663.9	268.5	275.8
				817.8	1387.8	2205.6	....	....	....	....	3166.9	4915.1	8082.0	....	....
				37.1%	62.9%	100%					39.2%	60.8%	100%		
B-1 Crushed Gravel 40 lb. per sq. yd.	Original	310.6	310.6	....	....	....	....	....	310.6	310.6	....	....	....	....	....
	1 Trip	454.7	492.5	144.1	181.9	326.0	46.4	58.6	408.0	665.0	97.4	354.4	451.8	31.4	114.1
	2 Trips	687.5	594.8	376.9	284.2	661.1	121.3	91.5	580.0	604.6	269.4	294.0	563.4	86.7	94.7
	3 Trips	516.9	535.5	206.3	224.9	431.2	66.4	72.4	660.7	781.9	350.1	471.3	821.4	112.7	151.7
	4 Trips	499.8	534.0	189.2	223.4	412.6	60.9	71.9	694.6	806.4	384.0	495.8	879.8	123.6	159.6
	5 Trips	350.5	508.0	39.9	197.4	237.3	12.8	63.6	614.2	890.5	303.6	579.9	883.5	97.7	186.7
	6 Trips	454.6	516.5	144.0	205.9	349.9	46.4	66.3	623.3	1137.8	312.7	827.2	1139.9	100.7	266.3
	7 Trips	453.8	600.9	143.2	290.3	433.5	46.1	93.5	838.3	1202.0	527.7	891.4	1419.1	169.9	287.0
	8 Trips	504.2	548.6	193.6	238.0	431.6	62.3	76.6	784.3	1070.9	473.7	760.3	1234.0	152.5	244.8
				1437.2	1846.0	3283.2	....	....	....	....	2718.6	4674.3	7392.9	....	....
				43.8%	56.2%	100%	....	....	....	....	36.8%	63.2%	100%	....	....

TABLE VI.—SERIES II—THE EFFECT OF SEVEN ROUND TRIPS OF A 10-TON ROLLER ON VARIOUS TYPES OF SIZE 8F AGGREGATES.

			On Flexible Base							On Rigid Base						
			Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent		Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent	
			Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers
No. 8F Limestone 40 lb. per sq. yd.	A-1	Original	319.9	319.9						324.7	324.7					
		After Rolling	782.3	871.2	462.4	551.3	1013.7	144.5	172.3	1038.4	1254.6	713.7	929.9	1643.6	219.8	286.4
	A-2	Original	256.3	256.3						256.9	256.9					
		After Rolling	546.1	481.0	289.8	224.7	514.5	113.1	87.7	760.5	1013.8	503.6	756.9	1260.5	196.0	294.6
	A-3	Original	238.8	238.8						255.1	255.1					
		After Rolling	357.7	425.7	118.9	186.9	305.8	49.8	78.3	605.3	841.8	350.2	586.7	936.9	137.3	230.0
	A-4	Original	243.4	243.4						224.3	224.3					
		After Rolling	460.8	591.4	217.4	348.0	565.4	89.3	143.0	688.0	1035.9	463.7	811.6	1275.3	206.7	361.8
	A-5	Original	313.3	313.3						315.7	315.7					
		After Rolling	952.0	1227.2	638.7	913.9	1552.6	203.9	291.7	1260.3	1966.8	944.6	1651.1	2595.7	299.2	523.0
	A-6	Original	249.4	249.4						292.2	292.2					
		After Rolling	609.8	663.2	360.4	413.8	774.2	144.5	165.9	758.4	910.5	466.2	618.3	1084.5	159.5	211.6
No. 8F Crushed Gravel 40 lb. per sq. yd.	B-1	Original	297.9	297.9						257.2	257.2					
		After Rolling	462.8	608.6	164.9	310.7	475.6	55.4	104.3	855.1	1109.6	597.9	852.4	1450.3	232.5	331.4
	B-2	Original	330.3	330.3						320.5	320.5					
		After Rolling	865.9	796.5	535.6	466.2	1001.8	162.2	141.1	987.8	1268.0	667.3	947.5	1614.8	208.2	295.6
	B-3	Original	307.4	307.4						343.9	343.9					
		After Rolling	669.2	752.1	361.8	444.7	806.5	117.7	144.7	1013.8	1175.6	669.9	831.7	1501.6	194.8	241.8
	B-4	Original	249.9	249.9						362.5	362.5					
		After Rolling	672.5	790.4	422.6	540.5	963.1	169.1	216.3	791.8	1190.7	429.3	828.2	1257.5	118.4	228.5
No. 8F Slag 40 lb. per sq. yd.	C-1	Original	281.1	281.1						259.6	259.6					
		After Rolling	513.5	617.7	232.4	336.6	569.0	82.7	119.7	976.3	1181.3	715.7	920.9	1636.6	275.7	354.7
					3804.9 44.5%	4737.2 55.5%	8542.2 100%					6522.1 40.1%	9735.2 59.9%	16257.3 100%		

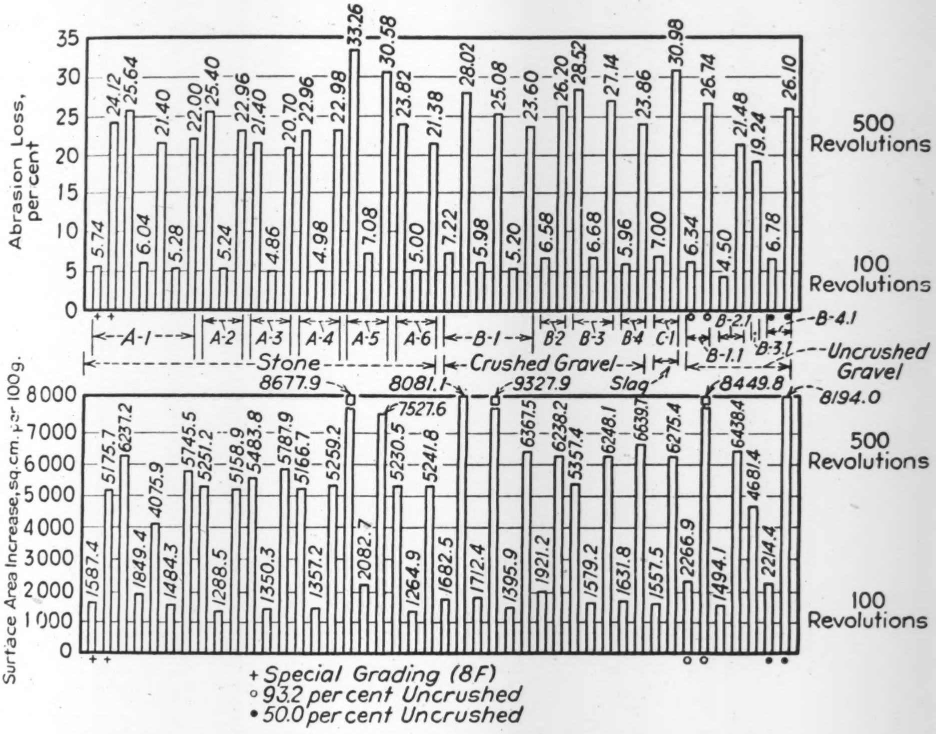

FIG. 3.—Los Angeles Abrasion Test Results Compared on the Basis of Abrasion Loss and Surface Area Increase.

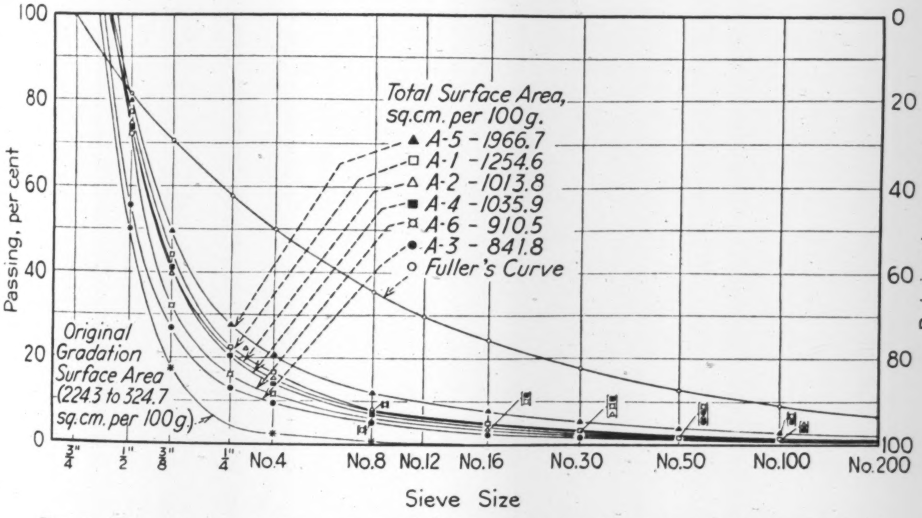

FIG. 4.—Degradation of Limestone Produced by 10-ton Roller Compared on the Basis of Gradation.

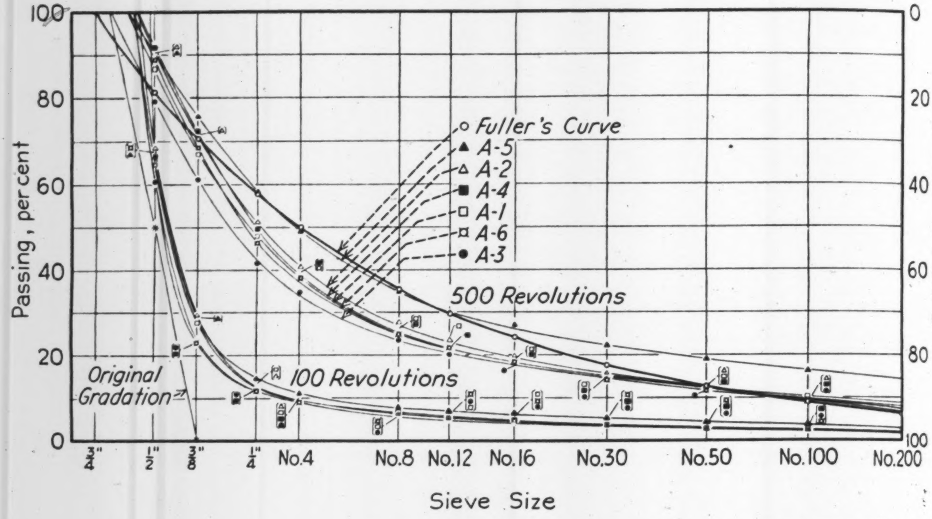

FIG. 5.—Degradation of Limestone Produced by Los Angeles Rattler Compared on the Basis of Gradation.

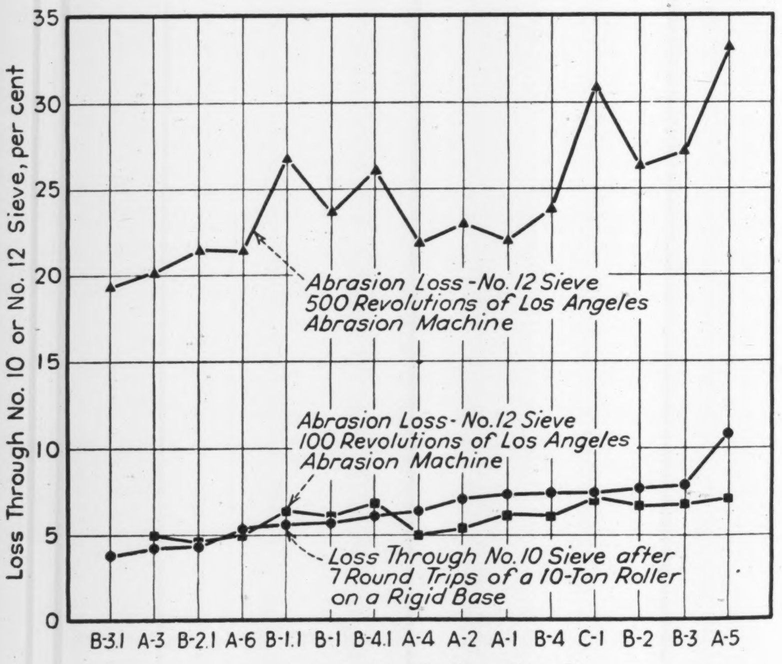

FIG. 6.—Degradation Produced by 10-ton Roller and Los Angeles Rattler Compared on the Basis of Abrasion Losses.

by the rear rollers was 63 per cent for the limestone and 56.2 per cent for the crushed gravel. On the rigid base the amount of degradation increased with the number of trips. For all passes on the concrete slab, the percentage of degradation produced by the rear rollers was 60.8 for the limestone and 63.2 for the crushed gravel. Nearly three times as much degradation was produced on the rigid base as upon the flexible one.

Effects of Type and Characteristics of Aggregate (Series II):

The degradation of six limestones, four crushed gravels and one blast-furnace slag, all size 8F, were compared after seven round trips of the 10-ton roller (Fig. 2). A summary of the results is shown in Table VI. See also Table XIII and Figs. 3, 4, 5 and 6 for data permitting comparisons of roller breakdown and losses in the Los Angeles tests.

TABLE VII.—COMBINATIONS OF AGGREGATE SIZES (LB. PER SQ. YD.).

Grading	Size 8F	Size 11	Total
No. 1	Los Angeles "B" Grading		40
No. 2	40	0	40
No. 3	35	5	40
No. 4	30	10	40
No. 5	0	40	40

An inspection of the data in Table VI shows that for both the rigid and flexible bases there was a wide range in ability of the aggregates from the different sources to resist crushing under the roller. Under the rear rollers on the rigid base the surface area increase was the least for A-3 limestone (230 per cent) and the greatest for A-5 limestone (523 per cent). The rating of the aggregates from the roller tests was approximately the same as from the Los Angeles tests. The rear rollers produced from 55 per cent (on the flexible base) to 60 per cent (on the rigid base) of the total degradation. Approximately twice as much degradation was obtained on the concrete base as upon the bituminous mat.

Effects of Gradation (Series III):

Limestone (A-2) and crushed gravel (B-2), of the gradings shown in Table VII, were subjected to seven round trips of the 10-ton roller.

There was less breakdown with the finer gradings than the coarser ones even though the original gradations were not entirely consistent, due to the difficulty encountered in spreading small quantities of aggregate (5 or 10 lb. per sq. yd.) uniformly. The results are summarized in Table VIII. An inspection of the data (Table VIII) shows that the change in surface area due to rolling appeared, on the whole, to increase somewhat with fineness of grading, although exceptions will be noted. However, in general, the percentage change in terms of the original surface area decreased with increase in fineness, thus indicating a lesser breakdown. These results indicate that chipping aggregate size 11 exerted a protective action against crushing when added to size 8F covering aggregate. This also suggests the possibility that a dense graded aggregate might be relatively free from degradation. In series III the breakdown resulting from the rear roller on the rigid base was 54.9 per cent (limestone) and 57.7 per cent (crushed gravel) of the total. The ratio of degradation on the rigid base to the flexible base was approximately 1.25—a lesser amount than found for the first two series.

Comparison of Crushed and Uncrushed Gravel (Series IV):

In this series of tests, size 8F gravels from four sources were used and subjected to seven round trips of the 10-ton roller. One 3-ft. section consisted of 100 per cent crushed gravel, adjacent to a section of uncrushed or partially un-

TABLE VIII.—SERIES III—THE EFFECT OF SEVEN ROUND TRIPS OF A 10-TON ROLLER ON VARIOUS GRADINGS OF AGGREGATE.

	Grading		On Flexible Base							On Rigid Base						
			Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent		Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent	
			Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers
A-2 Limestone 40 lb. per sq. yd.	No. 1	Original	223.3	223.3	....	....	....	....	....	219.7	219.7	....	....	....	....	....
		After Rolling	502.2	504.8	278.9	281.5	560.4	124.9	126.0	832.0	815.5	612.3	595.8	1208.1	278.7	271.2
	No. 2	Original	255.6	255.6	....	....	....	....	....	252.1	252.1	....	....	....	....	....
		After Rolling	616.8	594.6	361.2	339.0	700.2	141.3	132.6	855.4	1009.8	603.3	757.7	1361.0	239.3	300.6
	No. 3	Original	315.2	315.2	....	....	....	....	....	325.5	325.5	....	....	....	....	....
		After Rolling	651.4	548.4	336.2	233.2	569.4	106.6	74.0	880.1	1021.0	554.6	695.5	1250.1	170.4	213.7
	No. 4	Original	346.1	346.1	....	....	....	....	....	325.9	325.9	....	....	....	....	....
		After Rolling	546.5	572.9	200.4	226.8	427.2	57.9	65.5	844.0	1045.6	518.1	719.7	1237.8	159.0	220.6
	No. 5	Original	675.6	675.6	....	....	....	....	....	609.3	609.3	....	....	....	....	....
		After Rolling	1262.7	1071.9	587.1	396.3	983.4	86.9	58.7	1298.5	1461.7	689.2	852.4	1536.6	113.1	139.9
					1763.8	1476.8	3240.6					2977.5	3621.1	6593.6		
					54.5%	45.5%	100%					45.1%	54.9%	100%		
B-2 Crushed Gravel 40 lb. per sq. yd.	No. 1	Original	287.1	287.1	....	....	....	....	....	293.3	293.3	....	....	....	....	....
		After Rolling	613.2	615.8	326.1	328.7	654.8	113.6	114.5	907.8	1020.6	614.5	727.3	1341.8	209.5	248.0
	No. 2	Original	377.5	377.5	....	....	....	....	....	409.5	409.5	....	....	....	....	....
		After Rolling	954.5	879.9	577.0	502.4	1079.4	153.0	133.1	1065.2	1306.1	655.7	896.6	1552.3	160.1	218.9
	No. 3	Original	414.3	414.3	....	....	....	....	....	379.9	379.9	....	....	....	....	....
		After Rolling	772.6	844.5	358.3	430.2	788.5	86.5	103.8	1029.4	1398.7	649.5	1018.8	1668.3	171.0	268.2
	No. 4	Original	494.5	494.5	....	....	....	....	....	433.5	433.5	....	....	....	....	....
		After Rolling	982.8	923.1	488.3	428.6	916.9	98.7	86.7	1204.3	1449.2	770.8	1015.7	1786.5	178.0	234.3
	No. 5	Original	684.5	684.5	....	....	....	....	....	600.9	600.9	....	....	....	....	....
		After Rolling	1481.6	1490.3	797.1	805.8	1602.9	116.4	117.7	1590.3	1961.2	989.4	1360.3	2349.7	164.7	226.4
					2546.8	2495.7	5042.5					3679.9	5018.7	8698.6		
					50.5%	49.5%	100%					42.3%	57.7%	100%		

TABLE IX.—SERIES IV—COMPARISON OF CRUSHED AND UNCRUSHED GRAVEL ON THE BASIS OF SURFACE AREA INCREASE PRODUCED BY SEVEN ROUND TRIPS OF A 10-TON ROLLER.

			On Flexible Base							On Rigid Base						
			Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent		Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent	
			Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers
Crushed Gravel 40 lb. per sq. yd.	B-1	Original	406.0	406.0	....	....	....	....	....	402.2	402.2	....	....	....	....	....
		After Rolling	853.2	919.6	447.2	513.6	960.8	110.1	126.5	1185.4	1740.9	783.2	1338.7	2121.9	194.7	332.8
	B-2	Original	305.6	305.6	....	....	....	....	....	302.2	302.2	....	....	....	....	....
		After Rolling	593.1	817.5	287.5	511.9	799.4	94.1	167.5	1067.6	1015.4	765.4	713.2	1478.6	253.3	236.0
	B-3	Original	....	....	....	....	....	....	....	318.0	318.0	....	....	....	....	....
		After Rolling	....	....	....	....	....	....	....	810.1	1172.0	492.1	854.0	1346.1	154.7	268.6
	B-4	Original	312.2	312.2	....	....	....	....	....	291.8	291.8	....	....	....	....	....
		After Rolling	689.4	667.5	377.2	355.3	732.5	120.8	113.8	1020.4	1158.1	728.6	866.3	1594.9	249.7	296.9
					1111.9 44.6%	1380.8 55.4%	2492.7 100%					2769.3 42.4%	3772.2 57.6%	6546.9 100%		
Uncrushed Gravel 40 lb. per sq. yd.	B-1.1	Original	339.8	339.8	....	....	....	....	....	321.0	321.0	....	....	....	....	....
		After Rolling	635.4	590.1	295.6	250.3	545.9	87.0	73.7	922.8	1260.6	601.8	939.6	1541.4	187.5	292.7
	B-2.1	Original	....	....	....	....	....	....	....	327.5	327.5	....	....	....	....	....
		After Rolling	....	....	....	....	....	....	....	712.5	951.5	385.0	624.0	1009.0	117.6	190.5
	B-3.1	Original	317.3	317.3	....	....	....	....	....	314.1	314.1	....	....	....	....	....
		After Rolling	441.6	390.3	124.3	73.0	209.3	39.2	23.0	706.2	763.8	392.1	449.7	841.8	124.8	143.2
	B-4.1	Original	356.6	356.6	....	....	....	....	....	313.2	313.2	....	....	....	....	....
		After Rolling	591.6	714.1	235.0	357.5	592.5	65.9	100.3	982.4	1154.5	669.2	841.3	1510.5	213.7	268.6
					654.9 49.5%	680.8 50.5%	1347.7 100%					2048.1 41.8%	2854.6 58.2%	4902.7 100%		

TABLE X.—SERIES V—THE EFFECT OF THE NUMBER OF TRIPS OF A 5-TON ROLLER ON LIMESTONE AND CRUSHED GRAVEL.

			On Flexible Base							On Rigid Base						
			Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent		Surface Area, sq. cm. per 100 g.		Surface Area Increase, sq. cm. per 100 g.			Increase, per cent	
			Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers
A-1 Limestone Size 8F 40 lb. per sq. yd.		Original	232.6	232.6	....	....	....	....	....	293.1	293.1	....	....	....	....	....
		After 1 Trip	313.6	381.9	81.0	149.3	230.3	34.8	64.2	306.6	514.1	13.5	221.0	234.5	4.6	75.4
		Original	323.8	323.8	....	....	....	....	....	308.1	308.1	....	....	....	....	....
		After 3 Trips	328.8	480.6	5.0	156.8	161.8	1.5	48.2	401.5	683.9	93.4	375.8	469.2	30.3	122.0
		Original	298.0	298.0	....	....	....	....	....	288.2	288.2	....	....	....	....	....
		After 5 Trips	403.4	493.5	105.4	195.5	300.9	35.4	65.6	478.1	914.8	189.9	626.6	816.5	65.9	217.4
		Original	302.2	302.2	....	....	....	....	....	303.2	303.2	....	....	....	....	....
		After 7 Trips	415.2	684.2	113.0	382.0	495.0	37.4	126.4	564.1	1183.5	260.9	880.3	1141.2	86.0	290.3
		Original	458.2	458.2	....	....	....	....	....	452.5	452.5	....	....	....	....	....
		After 9 Trips	578.7	957.1	120.5	498.9	619.4	26.3	108.9	736.7	1482.9	284.2	1030.4	1314.6	62.8	227.7
					424.9 23.5%	1382.5 76.5%	1807.4 100%					814.9 21.2%	3134.2 78.8%	3976.1 100%		
Crushed Gravel Size 8F 40 lb. per sq. yd.	B-1	Original	321.6	321.6	....	....	....	....	....	402.2	402.2	....	....	....	....	....
		After 1 Trip	409.2	574.0	87.6	252.4	340.0	27.2	78.5	401.3	750.4	0.0	348.2	348.2	0.0	86.6
		Original	335.2	335.2	....	....	....	....	....	322.5	322.5	....	....	....	....	....
		After 3 Trips	348.1	691.0	12.9	355.8	428.7	3.8	106.1	486.3	1007.5	163.8	685.0	848.8	50.8	212.4
	B-4	Original	311.0	311.0	....	....	....	....	....	296.6	296.6	....	....	....	....	....
		After 5 Trips	404.0	627.0	93.0	316.0	409.0	29.9	101.6	589.0	1116.8	292.4	820.2	1112.6	98.6	276.5
		Original	303.6	303.6	....	....	....	....	....	321.2	321.2	....	....	....	....	....
		After 7 Trips	593.0	773.1	289.4	369.5	658.9	95.3	121.7	604.3	1536.7	283.1	1215.5	1498.6	88.1	378.4
		Original	377.7	377.7	....	....	....	....	....	326.1	326.1	....	....	....	....	....
		After 9 Trips	605.2	890.0	227.5	512.3	739.8	60.2	135.6	694.6	1732.3	368.5	1406.2	1774.7	113.0	431.2
					770.4 29.9%	1806.0 70.1%	2576.4 100%					1107.8 19.8%	4475.1 80.2%	5582.9 100%		

crushed gravel from the same source. The lithological composition of these gravels is given in Table I.

TABLE XI.—COMPARISON OF CHECK RESULTS ON MATERIALS FROM THE SAME SOURCE (SEVEN ROUND TRIPS OF 10-TON ROLLER).

Series	Materials	Increase in Surface Area, sq. cm. per 100 g.						Average Roller Speed, m.p.h.
		On Flexible Base			On Rigid Base			
		Front Roller	Rear Rollers	Both Rollers	Front Roller	Rear Rollers	Both Rollers	
I	A-1	128.4	186.9	315.3	640.4	815.6	1456.0	2.38
II	A-1	462.4	551.3	1013.7	713.7	929.9	1643.6	3.59
I	B-1	143.2	290.3	433.5	527.7	891.4	1419.1	2.38
II	B-1	164.9	310.7	475.6	597.9	852.4	1450.3	3.59
IV	B-1	447.2	513.6	960.8	783.2	1338.7	2121.9	2.21
II	A-2	289.8	224.7	514.5	503.6	756.9	1260.5	3.59
III	A-2	361.2	339.0	700.2	603.3	757.7	1361.0	2.45
II	B-2	535.6	466.2	1001.8	667.3	947.5	1614.8	3.59
III	B-2	577.0	502.4	1079.4	655.7	896.6	1552.3	2.45
IV	B-2	287.5	511.9	799.4	765.4	713.2	1478.6	2.21

TABLE XII.—TEST RESULTS OF DEGRADATION PRODUCED BY FRONT AND REAR ROLLERS COMPARED WITH THEORETICAL AMOUNT ON A PERCENTAGE BASIS.

	On Flexible Base		On Rigid Base		Aggregate Tested
	By Front Roller	By Rear Rollers	By Front Roller	By Rear Roller	
WORK DONE BY 10-TON ROLLER, PER CENT					
Series I	37.1	62.9	39.2	60.8	A-1 Limestone
	43.8	56.2	36.8	63.2	B-1 Gravel (Crushed)
Series II	44.5	55.5	40.1	59.9	All Materials
Series III	54.5	45.5	45.1	54.9	A-2 Limestone
	50.5	49.5	42.3	57.7	B-2 Gravel (Crushed)
Series IV	44.6	55.4	42.4	57.6	Crushed gravel
	49.5	50.5	41.8	58.2	Uncrushed gravel
Average	46.4	53.6	41.1	58.9	
Computed theoretical amount			40.7	59.3	
WORK DONE BY 5-TON ROLLER, PER CENT					
Series V	23.5	76.5	21.2	78.8	Limestone
	29.9	70.1	19.8	80.2	Gravel (Crushed)
Average	26 7	73.3	20.5	79.5	
Computed theoretical amount			32.8	67.2	

Results summarized in Table IX indicate that the crushed gravel broke down more than the uncrushed gravel. For example, the increase in surface area under the rear rollers of B-3 crushed gravel was 269 per cent, while with B-3.1 uncrushed gravel from the same source this increase was only 143 per cent. On the rigid base, the rear rollers produced 57.6 per cent of the total degradation of the crushed gravel and 58.2 per cent of the uncrushed gravel. Nearly 2.5 times as much degradation was produced on the concrete base as upon the bituminous mat. Approximately 1.3 times as much degradation occurred in rolling crushed gravel as when uncrushed gravel from the same source was used. As shown in Table I the crushed gravels contained a greater percentage of the harder particles, yet they broke down more under the roller. This would indicate that particle shape influences the amount of degradation, the round uncrushed particles being more resistant to crushing under the roller.

Effect of the Number of Trips of a 5-ton Roller (Series V):

Materials from the same source as in series I were used; however, since an insufficient amount of the B-1 crushed gravel was available, B-4 crushed gravel was substituted for the last three gravel sections. The number of trips of the 5-ton roller ranged from one to nine, inclusive. Samples were collected after one, three, five, seven, and nine round trips. Test results are summarized in Table X.

On both the flexible base and rigid base the surface area increased with the number of trips. Seven round trips produced from four to five times as much crushing as one round trip. On the rigid base the rear rollers were responsible for approximately 80 per cent of the surface area increase. Slightly more than twice as much degradation was produced on the rigid base as on the flexible one. In comparing the 5-ton and the 10-ton rollers, it was found that when limestone was rolled on the concrete base, the breakage under the 5-ton was from 55 to 80 per cent of that produced by the 10-ton roller.

Comparison of Check Results:

The tests were designed so that materials were duplicated in the various series to check results (Fig. 1). Table XI shows the comparisons of check results. It will be noted that the increases in surface area for materials from the same source were fairly consistent in the various series on the rigid base. As might be expected, results were not as consistent on the flexible base. It is believed that the temperature of the bituminous mat at the time of performing the tests affected the amount of work done on the aggregates. Another factor, the slight variation in original surface area of the aggregate samples in each test, affected the correlation of test results. As was found from series III, the greater the original surface area, the greater the increase in surface area. Considering inaccuracies which might arise in spreading, sampling and sieving the aggregates, the correlation of test results on the rigid base appear sufficiently close.

As a further check on the accuracy of the roller test results, a comparison was made between the actual amount of crushing done by each roller and the predicted amount as computed from roller weights and dimensions (Table XII). In computing the theoretical amount of work done by each roller, the amount of compaction under both front and rear rollers was assumed to be equal. Table XII shows that the average percentage of work done by each roller of the 10-ton machine on the rigid base checks within one per cent the amount predicted from computations. When aggregates are compacted on the flexible base, some of the work done is transferred into the base, and a smaller difference exists between the amount of work done by front and rear rollers. With the 5-ton roller, used only in series V, the actual and computed amounts of work done do not check as closely. This may be due to the fact that while the 5-ton roller is rated by the manufacturer as such, yet the total weight is listed as 6 tons.

LOS ANGELES TEST RESULTS

The results of the Los Angeles abrasion tests are given in Table XIII, and shown graphically in Fig. 3, both in terms of abrasion loss and surface area increase. The percentage of wear or abrasion loss at 100 revolutions varied from 4.5

TABLE XIII.—RESULTS OF LOS ANGELES ABRASION TESTS.

	A-1							A-2			A-3			A-4			A-5			A-6		
	Test No. 1[a]		Test No. 2	Test No. 3		Test No. 4		Test No. 1	Test No. 2		Test No. 1	Test No. 2		Test No. 1	Test No. 2		Test No. 1	Test No. 2		Test No. 1	Test No. 2	
	100 revolutions	500 revolutions	500 revolutions	100 revolutions	500 revolutions	100 revolutions	500 revolutions	500 revolutions	100 revolutions	500 revolutions	500 revolutions	100 revolutions	500 revolutions	500 revolutions	100 revolutions	500 revolutions	500 revolutions	100 revolutions	500 revolutions	500 revolutions	100 revolutions	500 revolutions
Per cent retained on ¾-in. sieve	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Per cent retained on ½-in. sieve	40.2	12.2	7.0	39.7	12.8	35.5	13.2	7.4	31.6	9.1	20.5	39.3	20.8	4.7	33.4	8.1	6.2	32.7	9.1	9.0	31.9	11.2
Per cent retained on ⅜-in. sieve	70.7	31.0	24.5	72.7	32.7	72.6	33.0	26.3	70.4	29.0	38.6	76.4	38.8	24.8	77.0	27.8	19.1	71.0	24.3	26.6	77.1	31.7
Per cent retained on ¼-in. sieve	86.2	50.3	45.2	85.9	53.7	87.4	52.1	46.3	87.3	48.8	56.4	88.2	58.4	49.0	88.2	50.3	36.6	85.4	41.6	48.1	88.3	53.7
Per cent retained on No. 4 sieve	89.4	59.1	55.0	89.1	63.0	90.3	62.0	55.8	90.5	59.2	64.3	91.0	65.1	59.5	91.0	61.1	46.1	88.8	51.0	57.6	91.3	61.8
Per cent retained on No. 8 sieve	93.5	72.3	70.7	92.8	75.4	93.7	74.8	70.4	93.8	72.7	75.8	94.2	76.4	74.4	94.3	74.4	62.1	92.0	65.0	72.6	94.4	75.2
Per cent retained on No. 12 sieve	94.3	76.5	75.9	93.9	79.4	94.7	78.6	75.5	94.7	77.5	79.7	95.2	79.9	78.8	95.1	78.5	67.9	93.0	70.0	77.4	95.1	78.1
Per cent retained on No. 16 sieve	95.0	79.0	78.8	94.5	81.7	95.4	81.0	78.3	95.4	80.1	82.0	95.7	82.0	81.2	95.6	80.7	71.2	93.7	72.8	80.2	95.7	81.6
Per cent retained on No. 30 sieve	96.0	83.5	83.6	95.3	85.5	96.3	85.0	83.1	96.4	84.4	85.8	96.4	85.5	85.2	96.3	84.3	76.7	94.8	77.5	84.6	96.5	85.9
Per cent retained on No. 50 sieve	96.7	86.3	86.9	96.1	88.0	97.0	87.5	87.1	97.2	87.4	88.8	97.2	88.2	88.3	97.1	87.0	80.8	95.5	81.0	88.4	97.2	88.4
Per cent retained on No. 100 sieve	97.2	88.9	89.3	96.8	90.7	97.5	89.9	91.1	97.7	90.5	90.8	97.7	90.2	91.2	97.7	90.4	83.9	96.3	83.9	91.2	97.7	90.9
Per cent retained on No. 200 sieve	97.7	94.7	91.7	97.5	96.2	98.0	92.4	93.7	98.4	93.8	92.5	98.2	92.0	93.4	98.2	93.6	88.7	97.2	91.3	93.8	98.4	93.2
T.S.A.[b]	1893.1	5481.4	6457.2	2069.4	4295.9	1704.3	5965.5	5471.2	1508.5	5378.9	5703.8	1570.3	6007.9	5386.7	1577.2	5479.2	8897.9	2302.7	7747.6	5450.5	1484.9	5461.8
S.A.I.[c]	1587.4	5175.7	6237.2	1849.4	4075.9	1484.3	5745.5	5251.2	1288.5	5158.9	5483.8	1350.3	5787.9	5166.7	1357.2	5259.2	8677.9	2082.7	7527.6	5230.5	1264.9	5241.8
Per cent loss on No. 12 sieve	5.74	24.12	25.64	6.04	21.4	5.28	22.0	25.4	5.24	22.96	21.4	4.86	20.72	22.96	4.98	21.98	33.26	7.08	30.58	23.82	5.0	21.34

	B-1						B-2		B-3			B-4		C-1		B-1.1		B-2.1		B-3.1		
	Test No. 1[a]		Test No. 2[d]		Test No. 3		Test No. 1		Test No. 1	Test No. 2		Test No. 1		Test No. 1		Test No. 1[e]		Test No. 1		Test No. 1	Test No. 1[f]	
	100 revolutions	500 revolutions	100 revolutions	500 revolutions	100 revolutions	500 revolutions	100 revolutions	500 revolutions	500 revolutions	100 revolutions	500 revolutions	100 revolutions	500 revolutions	100 revolutions	500 revolutions	100 revolutions	500 revolutions	100 revolutions	500 revolutions	500 revolutions	100 revolutions	500 revolutions
Per cent retained on ¾-in. sieve	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Per cent retained on ½-in. sieve	37.6	17.8	37.7	16.8	33.5	16.7	36.3	12.8	16.3	36.6	17.2	27.6	7.8	34.1	7.9	37.5	15.5	34.2	17.9	20.0	33.8	14.9
Per cent retained on ⅜-in. sieve	61.8	30.5	75.1	34.8	74.3	35.3	71.1	28.0	32.6	69.5	33.3	71.7	26.8	73.6	24.7	73.7	32.4	79.7	39.4	42.9	72.5	30.3
Per cent retained on ¼-in. sieve	79.9	45.3	86.9	51.3	88.3	53.4	85.4	48.5	48.3	84.7	48.7	86.1	49.7	85.0	41.0	86.1	49.6	88.9	56.5	59.7	85.0	48.2
Per cent retained on No. 4 sieve	85.8	54.2	89.6	58.4	91.1	61.0	88.4	56.1	55.9	88.8	56.8	89.6	59.0	88.1	50.0	89.5	57.5	91.8	64.6	67.4	88.0	56.7
Per cent retained on No. 8 sieve	91.5	67.8	93.2	70.2	94.0	72.7	92.4	69.5	68.0	92.4	69.1	93.1	72.3	92.1	64.7	92.8	70.1	94.8	75.8	78.2	88.6	70.6
Per cent retained on No. 12 sieve	92.9	72.7	94.2	73.9	94.8	76.6	93.5	74.4	72.3	93.4	73.2	94.2	76.8	93.2	69.6	93.7	74.0	95.5	79.2	81.5	93.3	74.6
Per cent retained on No. 16 sieve	93.6	75.3	94.8	76.1	95.3	78.7	94.2	77.2	74.6	93.9	75.5	94.9	79.2	94.0	72.9	94.2	76.1	95.9	81.1	83.4	94.0	77.1
Per cent retained on No. 30 sieve	94.8	79.8	95.6	79.6	96.1	82.1	95.2	82.1	78.8	94.8	79.7	95.7	83.4	95.3	79.3	94.9	79.2	96.5	84.4	86.5	94.7	80.6
Per cent retained on No. 50 sieve	95.6	82.9	96.4	82.4	96.7	84.8	96.0	85.4	83.5	96.0	83.9	96.6	86.2	96.5	84.7	95.5	82.0	97.0	86.6	89.2	95.7	83.9
Per cent retained on No. 100 sieve	96.4	85.9	97.0	85.7	97.4	87.4	96.3	88.2	90.1	96.5	85.4	96.9	87.2	96.9	88.8	95.6	83.5	97.1	87.6	91.8	96.3	86.1
Per cent retained on No. 200 sieve	97.5	88.7	97.7	89.4	98.3	92.2	97.5	92.3	94.4	98.3	93.3	97.9	91.2	98.5	93.9	96.8	88.7	98.0	91.4	94.0	96.9	88.3
T.S.A.[b]	1993.1	8391.7	1932.4	9547.9	1615.9	6587.5	2141.2	6458.2	5577.5	1799.2	6468.1	1851.8	6859.7	1797.5	6515.4	2486.9	8669.8	1714.1	6658.4	4901.4	2434.4	8414.0
S.A.I.[c]	1682.5	8081.1	1712.4	9327.9	1395.9	6367.5	1921.2	6238.2	5357.4	1579.2	6248.1	1631.8	6639.7	1557.5	6275.4	2266.9	8449.8	1494.1	6438.4	4681.4	2214.4	8194.0
Per cent loss on No. 12 sieve	7.22	28.02	5.98	25.08	5.2	23.6	6.58	26.2	28.52	6.68	27.14	5.96	23.86	7.0	30.98	6.34	26.74	4.5	21.48	19.24	6.78	26.1

[a] Special grading (8F).
[b] Total surface area (sq. cm. per 100 g.).
[c] Surface area increase.
[d] Results doubtful (5061 g. reported after 500 revolutions).
[e] 93.2 per cent uncrushed.
[f] 50 per cent uncrushed.

(B-2.1) to 7.0 (A-5), and at 500 revolutions from 19.24 (B-3.1) to 33.26 (A-5). Check results on the same materials showed fairly consistent results with a maximum variation at 500 revolutions of 4.24 in percentage of wear (A-1). Figure 3 shows a fairly good correlation between percentage of wear and surface area increase. However, at 500 revolutions so many fines are produced that any slight loss of minus No. 200 material affected the total computed surface area considerably. In plotting the resultant cumulative gradation of each aggregate after 500 revolutions in the rattler, an approximation of Fuller's[17] curve was obtained. From this, it would seem that almost any sieve size could be used for determining the percentage of wear or abrasion loss. The action of the Los Angeles rattler is that of a crusher and consequently follows the laws governing crushing.

Comparison of Roller and Los Angeles Test Results:

By plotting cumulative gradings, the amount of degradation produced by a 10-ton roller on the rigid base was compared with that produced by the Los Angeles rattler. Similar relationships were found with all types of aggregates tested. Typical examples are shown for limestone in Figs. 4 and 5. From these cumulative gradings, it was found that the aggregates rated in approximately the same order from both tests. However, at 500 revolutions in the rattler, five to ten times more surface area was produced than by seven round trips of the rear wheels of the 10-ton roller over the rigid base. The rollers broke down the larger particles into smaller ones without producing much dust, while the rattler working on all sizes of particles yielded more dust.

These results obtained by these two methods of crushing were also compared on the basis of abrasion losses (Fig. 6). This figure shows that the losses produced at 100 revolutions in the rattler were of the same order of magnitude and in approximately the same relationship as those produced by seven round trips of the rear wheels of the 10-ton roller over the rigid base. The losses at 500 revolutions were from 3 to 5 times greater in magnitude and showed a wider range in value for the aggregates.

CONCLUSIONS

From the results of these tests, the following conclusions are summarized:

1. More degradation occurred when aggregates were rolled on a rigid base than on a flexible base. An average of all tests showed that 2.3 times as much degradation was produced on the concrete slab as on the bituminous mat.

2. The results obtained on the rigid base were more regular than those on the flexible foundation, and when materials were duplicated in different series, satisfactory check results were obtained (Table XI).

3. The average work done for all the tests on the rigid base by the rear wheels of the 10-ton roller was 60 per cent as against 40 per cent by the front roller. Similarly, for the 5-ton roller, this average was 80 per cent as compared to 20 per cent by the front roller. This relative amount of crushing produced by the front and rear rollers of the 10-ton machine on the rigid base checked within 1 per cent the predicted amount as computed from roller weights and dimensions (Table XII).

4. On the rigid base, the amounts of degradation produced by both 5-ton and

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[17] W. B. Fuller and S. E. Thompson, "The Laws of Proportioning Concrete," *Transactions*, Am. Soc. Civil Engrs., Vol. LIX, December, 1907, p. 67.

10-ton rollers increased with the number of trips. On the flexible base, the amount of degradation produced by the rollers showed a tendency to reach a maximum after from two to five round trips of the 10-ton roller, but increased with the number of trips of the 5-ton machine, nine trips being the limit (Tables V and X).

5. Different types of aggregates from various sources showed a wide range in their resistance to crushing under the 10-ton roller (Table VI).

6. The rating of the aggregates from these road roller tests was in approximately the same order as that obtained from the Los Angeles abrasion tests. However, the amount of degradation or surface area increase at 500 revolutions in the rattler was five to ten times greater than that produced by seven round trips of the rear rollers of the 10-ton roller on the rigid base (Figs. 4 and 5).

7. When aggregates of various sizes, such as 8F ($\frac{3}{4}$-in. to No. 4) and 11 ($\frac{1}{2}$-in. to No. 8), were spread at the same quantity per square yard (40 lb.), the one which contained the most small-size particles showed the smallest percentage increase in surface area when tested under the roller. The chipping aggregate (size 11) exerted a protective action when added to size 8F covering (Table VIII).

8. With seven round trips of the 10-ton roller, approximately 1.3 times as much degradation was produced with crushed gravel as with uncrushed gravel (Table IX).

9. In comparing the 5-ton with the 10-ton roller, it was found that when limestone was rolled on the rigid base the increase in surface area under the 5-ton machine was from 55 to 80 per cent of that produced by the 10-ton roller.

10. The surface area increase from series II was found to be in fairly close agreement with that observed in previous surface treatment field samplings. This indicates that the rolling conditions encountered in these tests were approximately the same as those obtained in actual field conditions.

11. The cumulative grading of the aggregates after 500 revolutions in the Los Angeles rattler represented approximately a Fuller's curve.

12. The cumulative grading of the aggregates after 100 revolutions in the rattler was very similar to that after seven round trips under the rear rollers of the 10-ton roller on the rigid base. The road roller broke down the larger particles into smaller ones without producing a large amount of dust, while in the Los Angeles rattler work was done on all sizes of particles producing a greater quantity of dust.

13. A good correlation was found to exist between the losses after 100 revolutions in the rattler and after seven round trips of a 10-ton roller on a rigid base (Fig. 6).

In all the literature reviewed concerning the Los Angeles abrasion machine, no definite correlation of percentage of wear or abrasion loss with measured field results has been found. It is hoped that the results of these tests may serve that purpose and shed some light on the fundamental relations governing the physical forces of crushing and abrasion of aggregates, and improve our concepts concerning them. From these studies it appears that, both under construction procedure and under traffic, mineral aggregates follow a fixed manner of degrading. The degree of this degradation depends upon the amount of work exerted upon them.

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DISCUSSION

MR. H. F. KRIEGE.[1]—The paper presented by Mr. Shelburne has made several facts quite apparent. The first is that with a piece of field equipment, which is common to the construction of several important road types, he has been able to make a careful scientific analysis and present a well-organized set of data having definite value academically as well as practically. That, I think, is a fine contribution. Too often, as testing engineers and research men, we are apt to feel that nothing can be obtained of academic value unless it is done with some precise miniature piece of laboratory equipment.

The second fact is this: Frequently we hear the criticism that our investigational apparatus has no correlation with anything we know and use in the field, and I believe that that objection is often apt and pertinent in the realm of highway research. Mr. Shelburne's work has avoided that criticism entirely by its union of field equipment and laboratory test apparatus.

In the third place, Mr. Shelburne has pointed rather definitely to the value of the 100-revolution stage of the Los Angeles rattler test which, at the present time, is not being given sufficient appreciation. I think it is very much worthwhile to know that the total effects on aggregates of seven round trips of a roller approximate the *magnitude* of 100-revolution loss in the Los Angeles rattler. Also, he points out very clearly that the 500-revolution loss is so much higher than anything we encounter in actual construction conditions and use of the road that the significance of the test at this stage dwindles by that very fact. The Los Angeles rattler test has recently been given wide publicity without the value of such correlations and established facts with actual practice conditions. It is pleasing to note that the data presented in this paper establish both the weak and the strong points of the Los Angeles rattler test in predicting the behavior of aggregates to the conditions imposed by construction practices and by traffic.

MR. C. L. MCKESSON.[2]—It so happens that I was identified with the development of the Los Angeles rattler test from its inception in 1914 and 1915. It is, accordingly, quite a source of interest to me to see for the first time an actual comparison of degradation under service conditions with those obtained in the rattler. The purpose of the test was to control the output of a quarry operated by the so-called "glory hole" method. With a hole a quarter of a mile wide and 500 ft. deep, and shooting everything that came down from all sides, part of the rock was good and sound, and part of it was badly weathered. The thing that led us to devise the new rattler test was the extreme difficulty we had with the Deval rattler test; we could not pick a sample of pieces of proper sizes from the output.

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[1] Technical Director, The France Stone Co., Toledo, Ohio.

[2] Director of Engineering and Research, American Bitumuls Co., San Francisco, Calif.

If we picked an average sample of hard and soft rock, the quarry would maintain that only poor stone was abraded and the good stone alone remained, and that we should not include weathered stone. The rattler test was devised principally in the hope that it would provide a test comparable to service conditions and give us some measure of the probable performance. It is, accordingly, a great satisfaction, after 23 or 24 yr., to have this paper embodying results of tests for performance.

MR. SHREVE CLARK.[3]—I should like to ask Mr. Shelburne whether any consideration was given to the particle shape of the aggregate in making these various tests on the road.

MR. TILTON E. SHELBURNE.[4]—We compared crushed gravel and uncrushed gravel, but otherwise we did not take into consideration particle shape.

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[3] Engineer of Tests, Virginia Department of Highways, Richmond, Va.

[4] Research Engineer, Joint Highway Research Project, Purdue University, Lafayette, Ind.

DISINTEGRATION OF FACE BRICK BY CRYSTALLIZATION OF SOLUBLE SALT*

BY J. M. HARDESTY[1]

SYNOPSIS

This report covers a study to determine the cause of the disintegration of the face brick in a building only a few years old. For this study, selected samples were cut from the building and subjected to freezing-and-thawing tests and examined chemically and microscopically for the presence of soluble salts. The results indicate that the observed weathering was not due to frost action but to the formation of crystals of calcium sulfate on and just underneath the exposed face of the brick.

Of the various weathering agents that affect masonry, the crystallization of soluble salts is often mentioned in the literature although but few actual cases have been reported.[2] Consequently this study of the disintegration of the brick in a relatively new building in the metropolitan New York area may be of interest, since the active agent here was found to be calcium sulfate.

It is well known that burned clay ware may contain appreciable amounts of soluble salts which may effloresce and cause spalling and disintegration of the clay body. Lovejoy[3] found soluble salts in brickwork and showed that in general they existed in the body of the brick; he minimizes the importance of the mortar as a source of the salts. McIntyre,[4] in his studies of the durability of clay building materials, found large amounts of soluble salts in analyzing the efflorescence on common building brick. Palmer[5] describes the conversion of the carbonates of calcium and magnesium into their soluble sulfates by the action of sulfur trioxide during the firing process. Other investigators, notably Jackson[6] and Butterworth,[7] have pointed out that in general, the quantity of soluble salts decreases at the higher burning temperatures.

History of the Building:

The building involved in the current study is a three-story structure which

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[*] The presentation of this paper at the annual meeting was sponsored by Committee C-15 on Manufactured Masonry Units.

[1] Member of Technical Staff, Bell Telephone Laboratories, New York City.

[2] Discussion by C. C. Connor of paper by J. W. McBurney and D. E. Parsons, "The Wick Test for Efflorescence of Building Brick," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 338 (1937).

[3] E. Lovejoy, "Scumming and Efflorescence," pamphlet published by F. S. Hees, Columbus, Ohio (1907).

[4] W. A. McIntyre, "Factors Governing the Durability of Clay Building Materials," *Transactions*, Ceramic Soc. (London), Vol. 28, p. 101 (1929).

[5] L. A. Palmer, "Cause and Prevention of Kiln and Dry-House Scum and of Efflorescence on Face-Brick Walls," *Technologic Paper No. 370*, Nat. Bureau Standards (1928).

[6] F. G. Jackson, "A Chemical Study of the Absorption of Sulphur Dioxide from Kiln Gases by Ceramic Ware," *Journal*, Am. Ceramic Soc., March, 1926, Vol. 9, p. 154.

[7] B. Butterworth, "Some Effects of Soluble Salts in Clay Products," *Transactions*, Ceramic Soc. (London) Vol. 36, p. 233 (1937).

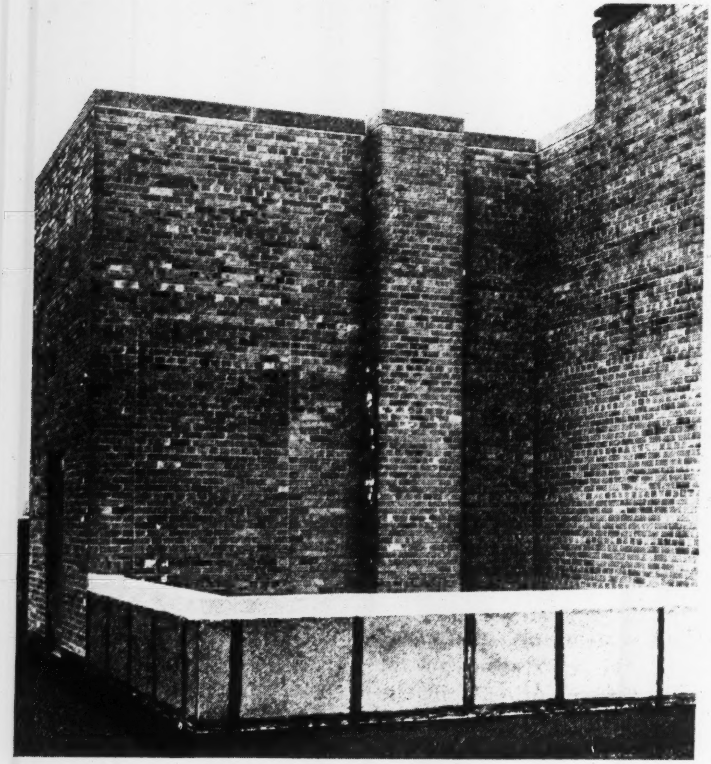

FIG. 1.—Penthouse Wall Showing General Distribution of the Spalling.

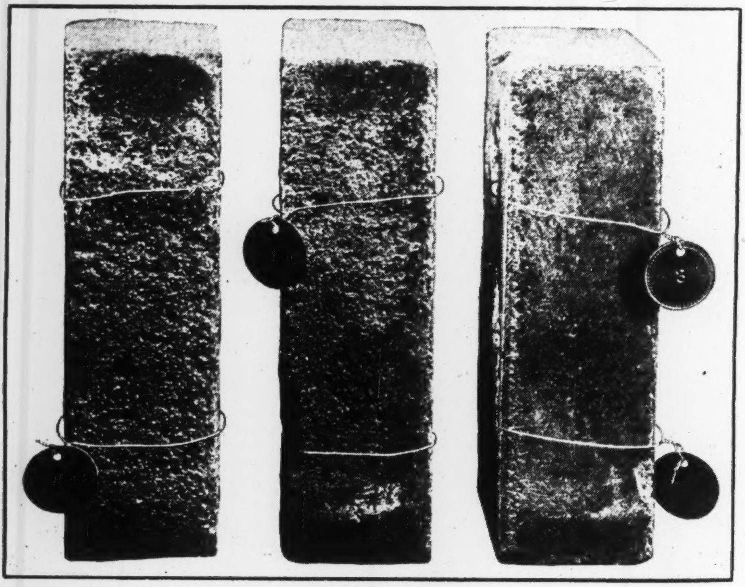

FIG. 2.—Spalled Brick from Building Showing Extent of Pitting.

was erected in 1931; the building plans, however, provide for its ultimate extension to eighteen stories. The brick used in the construction of the building was side cut, flash finish, salmon pink colored fireclay face brick ranging in shade from a light to a dark salmon pink.

Shortly after the brickwork was completed, the walls started to effloresce quite badly. In 1934, it was observed that many of the lighter colored bricks were affected by surface spalling and were changing to a buff or yellowish gray color. By the fall of 1935, some of the darker colored bricks also were beginning to spall. This spalling has now progressed to such an extent that the original faces of a large number of the bricks have entirely disappeared, and more than 50 per cent of all the bricks are showing some surface erosion. Figure 1 illustrates the general condition of all the walls in the building and Fig. 2 illustrates the spalling in more detail.

Physical Properties of the Brick:

In the spring of 1936, twelve bricks representative of the color range and degree to which weathering had progressed were removed from the building for test purposes. These bricks were all stretchers in the wall, so that each brick had one exposed face and one unexposed face. The mortar adhering to the unexposed face, sides, and ends was removed in such a manner as not to mar or scratch the original finish of the brick. This was done so that in making freezing-and-thawing tests there would be an opportunity to compare the two faces during the progress of the test. For reference purposes, these bricks were numbered 1 to 12. At a later date, three other bricks were obtained; these were numbered 13, 14 and 15. Number 13 was a brick left over from the group obtained to replace the twelve bricks taken from the building. Numbers 14 and 15 were bricks taken from the original panel submitted by the supplier as samples to the architect. The fifteen specimens are described briefly in Table I.

TABLE I.—SUMMARY OF RESULTS OF PHYSICAL TESTS OF BRICKS.

Sample	Extent of Spalling on Exposed Face	Original Color	Quantity of Soluble Salts[a]	Modulus of Rupture, psi.	Moisture Absorption, per cent		Saturation Coefficient (C24/B5 Ratio)	Loss in Weight 74 Cycles Freezing and Thawing, per cent	Compressive Strength, psi [c]
					24 hr., Room Temperature	5 hr., Boiling			
No. 1......	90%, deeply pitted	Light salmon pink	Abundant	565	9.8	14.9	0.65	0.58	4200
No. 2......	50%	Light salmon pink	Abundant	874	9.8	13.1	0.75	0.36	4900
No. 3......	25%	Light salmon pink	Abundant	788	10.0	13.4	0.75	1.43[b]	....
No. 4......	Several small spots	Salmon pink	Moderate	....	8.9	12.8	0.69	0.18	5850
No. 5......	Slight	Salmon pink	Trace	944	7.8	11.7	0.67	0.26	6600
No. 6......	Slight	Dark salmon pink	Trace	1343	7.7	11.1	0.69	0.34	7350+
No. 7......	None	Dark salmon pink	Trace	1340	7.2	10.7	0.67	0.25	7350+
No. 8......	None	Dark salmon pink	Trace	1080	8.3	11.8	0.70	0.46	6150
No. 9......	Slight	Salmon pink	Abundant	1065	8.3	12.1	0.69	0.11	....
No. 10......	None	Light salmon pink	Moderate	886	8.7	13.3	0.66	0.18	5000
No. 11......	None	Dark salmon pink	Abundant	....	7.6	12.1	0.63	0.21	....
No. 12......	None	Dark salmon pink	Trace	1215	7.1	10.7	0.66	0.26	6900
No. 13 New brick	None	Salmon pink	Abundant	....	...	....	....	....	6900+
No. 14	None	Light salmon pink	Abundant	....	...	....	....	....	....
No. 15	None	Salmon pink	Abundant	....	...	....	....	....	6700+

[a] For definition of classifications used in the wick test, see text.

[b] A large area of the face of sample 3 spalled off at the end of the sixty-first cycle.

[c] The plus (+) signs indicate that these samples did not fail under the maximum load of the testing machine.

The "wick test" was employed to determine the presence of soluble salts in the brick. This test was carried out as described by McBurney and Parsons,[8] except that the quantity of salts deposited on the surface of the bricks was rated by visual inspection as none, trace, moderate or abundant. These classifications of the amount of efflorescence are defined as follows:

None.—No observable difference in the appearance of the brick.

Trace.—A slight amount of efflorescence but not enough to affect materially the appearance of the brick surface.

Moderate.—Distinct coating but the color of the brick still visible under the efflorescence.

Abundant.—The original color of the brick masked by the efflorescence.

The results of this test are given in Table I.

The physical properties of the brick, as determined in accordance with standard procedure,[9] are also given in Table I.

In general, after making the modulus of rupture tests, the larger and less disfigured halves of brick resulting from this test were subjected to cycles of freezing and thawing. This test was carried out as described by McBurney[10] and was continued for 74 cycles. At the end of this period there was no observable change in the surface of the bricks as determined by photographs taken before and after test. The loss in weight is given in Table I.

Chemical and Microscopic Examination of the Brick:

For chemical and microscopic examination, two types of specimens were selected: (1) a typically weathered brick which was cut out of the building in such a manner as to keep intact the mortar surrounding it, and (2) thin chips chiseled from the exposed face of about a dozen weathered bricks in the building.

The whole brick was subjected to a modified wick test in which the specimen was placed face up in a shallow dish of distilled water. After four days, the evaporating water had deposited on the exposed face a white crystalline powder. Chemical analysis of this deposit showed that it consisted wholly of calcium sulfate.

A qualitative analysis of a water extract of the same brick showed the presence of a considerable amount of calcium sulfate, no other water-soluble substance being present in any appreciable quantity.

At the conclusion of the original wick tests discussed above, the salt deposits on samples 1 to 12 and on sample 13 were analyzed. The results showed the deposit on sample 13 to be calcium sulfate and the deposit on samples 1 to 12 to be a mixture of calcium and sodium sulfates.

Microscopic examination of the brick chips revealed segregated lumps of calcium sulfate underneath the face of the bricks. Some of these lumps were as large as 1 mm. in diameter, and all of them were made up of small crystals which would fly from the lump when it was touched by a probe, suggesting a strained condition. This indicates that the calcium sulfate was not sintered during the firing process in the manufacture of the brick.

Further examination of the brick chip specimens revealed certain of these calcium sulfate lumps which showed evidence of having started to dissolve. Also, several cases of actual spalling were observed. In each of these cases, a small flake of the brick surface was in the process of being separated from the brick. When these flakes were lifted and their underside examined, a small crystal of calcium sulfate was found.

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[8] J. W. McBurney and D. E. Parsons, "The Wick Test for Efflorescence of Building Brick," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 332 (1937).

[9] Standard Methods of Testing Brick (Modulus of Rupture, Compressive Strength, Absorption) (C 67 - 37), 1937 Supplement to Book of A.S.T.M. Standards, p. 78.

[10] J. W. McBurney, "The Weathering of Structural Clay Products: A Review," *Proceedings*, Am. Soc. Testing Mats., Vol. 31, Part II, p. 745 (1931).

Discussion of Test Results:

As shown in Table I, the bricks used in this building meet all the requirements for grade *SW*[11] brick. The freezing-and-thawing tests indicate that the observed weathering was not due to frost. The results of this test confirm the adequacy of the requirements for grade *SW* brick as insurance against failure by frost action.

The wick test is a rough guide as to the soluble salt content of a brick and, as shown by McBurney and Parsons,[8] provides a convenient means of determining whether a brick is likely to effloresce in a masonry wall. The following arrangement of the wick test data for samples 1 to 12 is of interest in that it shows a quite definite correlation between soluble salt content and disintegration of the bricks in service. In this summary each X represents one sample.

Condition of Brick Surface	Quantity of Soluble Salts			
	None	Trace	Moderate	Abundant
90 per cent of face spalled				X
50 per cent of face spalled				X
25 per cent of face spalled				X
Slight spalling		XX	X	X
No spalling		XXX	X	X

This table reveals that where the wick test shows no more than "moderate" efflorescence, the disintegration in service has been slight.

The results of the wick tests and the chemical analyses indicate that the bricks contain calcium sulfate in a soluble form. The main source of the salt, as indicated by microscopic examination of the body of the bricks and by chemical analysis of the unused sample 13, appears to be within the body of the bricks themselves and not in the mortar or the back-up materials.

The results of the microscopic examination of the brick specimens suggest the following explanation of the mechanism of the spalling action: During rainy seasons the bricks absorb moisture and this dissolves some of the calcium sulfate. Then, in dry periods, the solution moves by capillarity toward the drier exposed face of the brick wall. As the solution nears the face, it becomes concentrated due to evaporaton of the water through the surface pores and in time a thin layer of minute crystals forms just beneath the brick surface.[12] The mechanical force exerted by these crystals as they accumulate causes a spalling off of thin flakes of the brick surface.

Summary:

The facts determined by this study indicate that the observed weathering of the brick in this building is not due to frost action but to the formation of crystals of calcium sulfate on and just underneath the exposed face of the bricks. Also, that the source of the calcium sulfate is in the body of the brick itself and that it occurs in a soluble form.

Acknowledgments:

The author wishes to acknowledge the cooperation of D. E. Parsons, chairman of Committee C-15 and J. W. McBurney, Chairman of Subcommittee II on Clay Building Brick, in planning the tests on the physical properties of the brick. The microscopic work was done by H. W. Hermance and G. P. Rowland of the Chemical Department of the Bell Telephone Laboratories, Inc.

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[11] Tentative Specifications for Building Brick (Made from Clay or Shale) (C 62 - 37 T), *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 733 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 514.

[12] A. P. Laurie and John Milne, "Evaporation of Water and Salt Solutions from Surfaces of Stone, Brick, and Mortar," *Proceedings*, Royal Soc. of Edinburgh, Vol. 47, p. 52 (1926–1927).

DISCUSSION

Mr. F. O. Anderegg.[1]—I should like to agree with what Mr. Hardesty has said about the destructive action of calcium sulfate which crystallizes within the structure and causes efflorescent crystal pressure. Millions of dollars of damage is being done to our structures every year by this phenomenon. I should like to point out, however, another source that must be taken into consideration, and that is the fact that our winter rain waters are slightly acidic due to sulfuric acid from burning coal. When these waters strike a structure, sulfuric acid is drawn in and forms this calcium sulfate. An example of that is shown in the accompanying Fig. 1. of a structure in Ohio. The same thing holds true throughout the entire northeastern part of the country. You can see the white line of efflorescent material, due to winter rain water soaking into the wall and calcium sulfate being formed, which, by its crystal pressure, produces some of these disintegrations. In Fig. 2 is shown a parapet wall that fell to pieces very readily. Figure 3 is another example. The same thing happens to concrete all over the country.

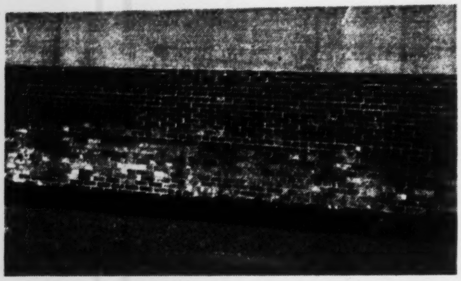

Fig. 1.—Parapet Wall Disintegrating Due to Calcium Sulfate, the Sulfuric Acid Having Come from Winter Rain or Snow.

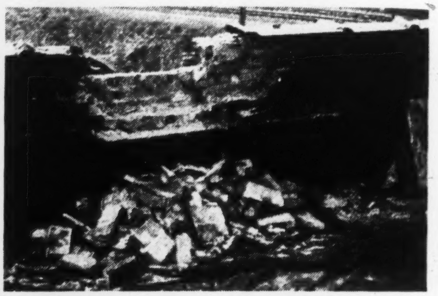

Fig. 2.—Badly Disintegrated Parapet Wall Caused by Sulfate Crystal Growth.

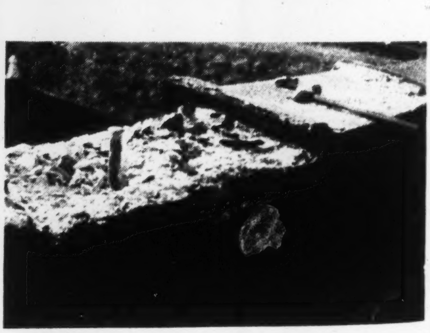

Fig. 3.—Mortar So Badly Disintegrated that It Offers Little Resistance to Penetration of the Chisel.

I should like to ask Mr. Hardesty whether the mortar joints were also becoming disintegrated due to efflorescence. Efflorescence on the mortar joints indicates that they were probably starting to disintegrate.

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[1] Consulting Specialist on Building Materials, Newark, Ohio.

MR. J. M. HARDESTY.[2]—There has been no observed disintegration of the mortar, although there is efflorescence on the mortar.

MR. H. R. STALEY.[3]—I should like to ask Mr. Hardesty what kind of mortar was used in laying the brick and whether they were laid in the winter or the summer.

MR. HARDESTY.—The mortar was a 1:1:6 mix. The lime used was a dry hydrated lime. I think records will show that the brickwork of this building was completed late in the fall.

MR. J. W. MCBURNEY.[4]—Mr. Hardesty stated that these brick complied with the physical requirements for grade SW, which is the highest grade indicated in the Tentative Specifications for Building Brick (Made from Clay or Shale) (A.S.T.M. Designation: C 62 - 37 T)[5] from the standpoint of resistance to weathering. The fact that these bricks proved unsatisfactory when exposed to weathering for a few years quite properly raises a question as to the adequacy of Tentative Specifications C 62. In defense of these specifications, however, it should be noted that the depth of spalling was slight. It would seem probable that this amount of disintegration would have attracted little or no attention, or would not have been regarded as objectionable, if it were not that the brick had a surface "flashing" color of a quite different shade from that of the body of the brick. Am I correct in understanding that this spalling of the face produced a marked color contrast with the unspalled portion?

MR. HARDESTY.—Mr. McBurney is correct in his assumption that the spalling has made a marked change in the color of the brick. It is probably true that even though the bricks had not changed color, the problem would have attracted attention and been considered serious since the building plans call for the addition of several floors to the present structure. At the time of the first extension, it would, of course, be necessary to decide whether to use the same brick for architectural reasons or to select some other type of brick which might have better weathering qualities.

MR. C. C. CONNOR.[6]—I am familiar with the building where the spalled brick condition exists which is reported by Mr. Hardesty. While this condition is interesting as a technical problem, it also has a serious economic aspect. The building is designed for fifteen additional stories, and the first addition made will necessitate a decision as to what to do with the large areas of spalled brickwork, and how to obtain a good appearance. The only solution appears to be the removal of the face brick on the three existing stories, and a conservative estimate of the cost of this operation is $50,000. This particular building is the worst of a group of five having similar spalled brick conditions, although the type of brick varies; and while the others have not been thoroughly studied, salt crystallization appears to be the common cause.

There can be little question of the immediate importance of developing requirements to be included in the standard specifications for brick which will protect the consumer against brick disintegration of this type.

MR. HARDESTY (*author's closure by letter*).—The action of sulfur oxidation compounds, as pointed out by Anderegg above and by others,[7] is without doubt one of the causes of the rapid decay of masonry. This type of action was considered in the study of the building under investigation. Samples of the brick removed from the structure were subjected to several different atmospheric concentrations of SO_2 under cyclic moist and dry conditions in an effort to duplicate the observed weathering. While one sample did show a slight progressive action of the surface spalling, it was not sufficiently pronounced after 50 cycles to justify continuation of the tests.

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[2] Member of Technical Staff, Bell Telephone Laboratories, New York City.

[3] Assistant Professor of Building Construction, Massachusetts Institute of Technology, Cambridge, Mass.

[4] Senior Technologist, National Bureau of Standards, Washington, D. C.

[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part I, p. 733 (1937); also 1938 Book of A.S.T.M. Tentative Standards, p. 514.

[6] Assistant Engineer, New Jersey Bell Telephone Co., Newark, N. J.

Mr. McBurney's defense of the present Tentative Specifications C 62 – 37 T would probably be justified for the one case given in this report if it really is a special case. Of seven other buildings having spalled brickwork, which the author has observed, preliminary study on four of them has indicated the active agent to be crystallization of soluble salts. In some of these cases, also relatively new buildings, the spalling has not been slight but has progressed to a depth of $\frac{1}{8}$ to $\frac{3}{16}$ in. Also tests on samples of the brick used in one of them indicates that the brick would have passed these tentative specifications as grade SW. Consequently, it seems the general question of whether or not these specification requirements for SW brick are really sufficient to assure against failure by other agents of weathering besides freezing and thawing is still unanswered.

The seriousness of the economic side of this general problem has been discussed at length by investigators here and abroad. Mr. Anderegg in his discussion states in general terms his estimate of the loss to owners each year from sulfur oxidation compounds carried by snow and rain. Mr. Connor points out the probable cost to replace the defective brickwork under investigation. This figure of $50,000 seems even larger when it is considered the owners have no specification under which they can purchase new brick with assurance that the present trouble will not recur.

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[7] Symposium on Weathering Characteristics of Masonry Materials, *Proceedings*, Am. Soc. Testing Mats., Vol. 31, Part II, p. 715 (1931).

PHOTOELASTIC ANALYSIS OF A PRESTRESSED BEAM

By F. O. Anderegg,[1] Royal Weller[2] and B. Fried[3]

Synopsis

With the aid of photoelastic analysis it is shown that the total prestress on a beam is equal to the total loading stress when the compression in the bottom fiber is just neutralized. At that stage, the directions of principal stresses are displaced 10 deg. and 80 deg. from the vertical and horizontal directions, respectively, so that the principal shears will then make angles of 35 and 55 deg. on the opposite side of the vertical. Advantages of prestressing reinforced ceramic beams include: immediate use of the steel as soon as load is applied, more effective use of the ceramic material so that a smaller section is needed, and noteworthy increase in stiffness.

To be able to explain more satisfactorily the principles involved in prestressing simple beams,[4] additional information has been obtained as to the behavior of such a beam under center loading with the aid of photoelastic analysis.[5] A phenol-formaldehyde resin (Bakelite BT-61-893) model was used and the work was done with the equipment of the Ohio State University Engineering Experiment Station. The model was first loaded in flexure, giving the usual pattern shown in Fig. 1. It was then placed in the straining frame of Fig. 5 and prestressed in such a way that the stress at the top fiber was zero, while at the bottom it was under compression. The stress pattern, reproduced photographically, is given in Fig. 2. A load was then applied to the top of the model at the center until the compressive stress in the bottom fiber was just neutralized and the fringe pattern is given in Fig. 3. Additional load then placed the bottom of the center part of the beam in tension as shown in Fig. 4.

The stress distribution of the prestressed beam, loaded centrally in flexure was then examined with plane polarized white light and by step-wise successive rotation of the polarizers, and the family of isoclinic lines reproduced in Fig. 6 was obtained. Frocht[6] has published the isoclinic pattern for a loaded, unprestressed beam, in which the isoclinic lines tend to cluster near the neutral axis, since in that neighborhood the stresses approach zero and have no specific direction. When the neutral region is depressed to the lower edge of the beam by prestressing and subsequent

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[1] Consulting Specialist on Building Materials, Newark, Ohio.

[2] Instructor in Physics, The Ohio State University, Columbus, Ohio.

[3] Engineering Experiment Station, The Ohio State University, Columbus, Ohio.

[4] F. O. Anderegg and C. L. Dalzell, "Pre-Stressed Ceramic Members," *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part II, p. 447 (1935).
F. O. Anderegg, "Super-Ceramic Building Members," *Journal*, Am. Ceramic Soc., Vol. 20, p. 77 (1937).
F. O. Anderegg, "Progress in Pre-Stressing Structural Clay Products," *Bulletin*, Am. Ceramic Soc., Vol. 18, (1939).

[5] A good description is given by Max M. Frocht, "Recent Advances in Photoelasticity," PhD. Thesis, University of Michigan (1931).

[6] Max M. Frocht, "Photoelastic Investigation of Shear and Bending Stresses in Centrally Loaded Beams," *Engineering Bulletin*, Carnegie Institute of Technology (1937).

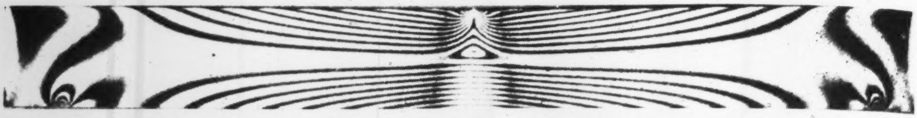

FIG. 1.—Beam Loaded in Flexure, No Prestress.

Neutral "axis" is point near center of beam enclosed within the triangular fringe.

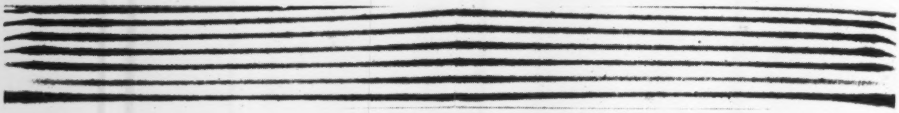

FIG. 2.—Prestressed Beam.

Top edge is under zero stress.

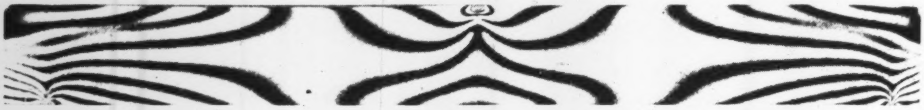

FIG. 3.—Prestressed Beam Loaded Until Prestress in the Center of the Bottom Is Just Neutralized.

The small dark fringe at that point is the neutral "axis."

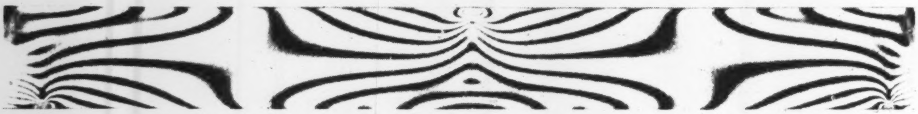

FIG. 4.—Load Applied to Put Bottom in Tension, Raising the Neutral "Axis" Which Is the Third Fringe from the Bottom.

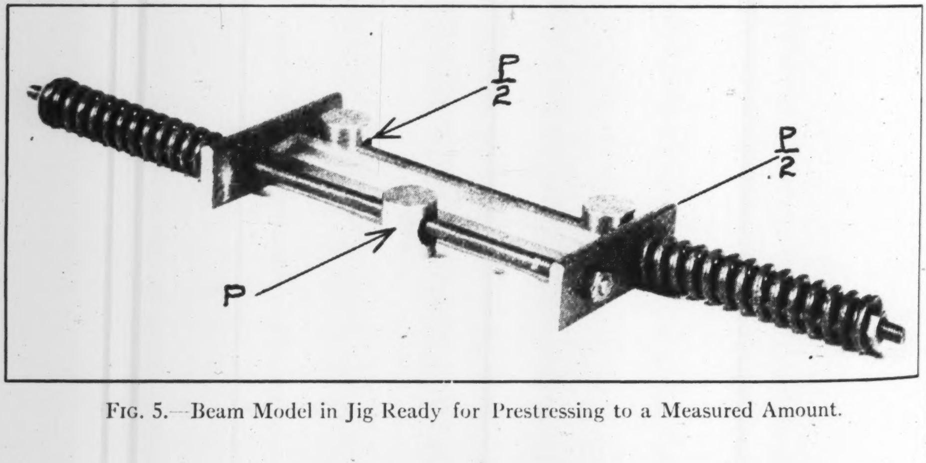

FIG. 5.—Beam Model in Jig Ready for Prestressing to a Measured Amount.

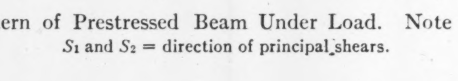

FIG. 6.—Isoclinic Pattern of Prestressed Beam Under Load. Note simplicity of pattern.

S_1 and S_2 = direction of principal shears.

loading, however, this clustering of isoclinics is likewise depressed to the lower edge and the 10-deg. and 80-deg. isoclinics cover the two sides of the beam respectively. This indicates that the directions of the principal stresses are displaced 10 deg. from the vertical and horizontal directions, respectively, and the principal shears will then make angles of 35 deg. and 55 deg. on opposite sides of the vertical. In effect, this corresponds to splitting a simple beam along the neutral plane and considering the prestressed beam to be equivalent to the upper part. This was determined by applying different degrees of prestress followed by exactly neutralizing the stress in the bottom fiber. The stress in the bottom fiber due to the bending loading is given by the usual formula for center loading

$$S_1 = 3\,WL/2bd^2$$

where W = the load,
L = the length of the beam between supports, and
b and d = the breadth and depth of the beam.

The stress of preloading has two components: (1) that due to bending, or camber produced:

$$S_2 = 3(F' - F)h/bd^2$$

where
F = the force applied by the top spring,
F' = the force applied by the bottom spring, and
h = the distance between springs.

(2) the direct stress

$$S_3 = (F + F')/A$$

where A = the area of the section.

NEUTRALIZATION OF PRESTRESS.

Phenol resin beam, $l = 5.62$ in., $b = 0.253$ in., $d = 0.642$ in.
Distance between supports = L = 4.875 in.
Distance between springs = h = 1.406 in.

	F, lb.	F', lb.	W, lb.	S_1, lb.	S_2, lb.	S_3, lb.	$S_1 - (S_2 + S_3)$, per cent
No 1....	83.4	89.0	18.7	1295	226	1060	9 or 0.7
No.2....	94.6	128.0	38.1	2640	1347	1365	72 or 2.7
No.3....	117.0	150.0	44.4	3070	1333	1640	97 or 3.2

By applying the prestressing load through knife edges (not shown in Fig. 5) the forces could be applied and measured with adequate accuracy. The results seem to indicate that the calculation previously made in the paper presented before the A.S.T.M.[4] is justified.

Three marked advantages are obtained through prestressing:

1. In any ordinarily reinforced beam, whether brick or concrete, the mortar or concrete around the reinforcing is initially in tension due to shrinkage, while the steel is in compression. On applying the load, by the time the steel takes up the tensile load, the mortar will practically have failed. It is for this reason that in designing reinforced beams, no credit can be given to the tensile strength of the mortar. In a prestressed beam, on the other hand, the mortar (and ceramic material) are not in tension, but in compression, while the steel is in tension and immediately resists bending due to loading.

2. In a prestressed beam a much more effective use of the ceramic material (or concrete) is obtained, the neutral axis disappearing out of the section during loading. The area under compression increases to the whole section and advantage is taken of that outstanding property of well-burned ceramic material, its great compressive strength. A corallary is to use materials of highest compressive strength for prestressed beams. In this way only half the section, or less, is required to carry a given load.

3. The very considerable *stiffness* that has been observed in experimenting with these beams is a noteworthy feature. At first sight it is a little difficult to account for this. It must be due to the difference in the moduli of elasticity in compression and in tension for brittle, in-

organic and non-metallic materials. It is true that few experimental tensile moduli are available to indicate that such a difference does occur, but it is supported by the following: The difference between tensile and compressive strengths of these materials is apparently mostly caused by discontinuities, at the apices of which stress concentration is very great when in tension, being often of the order of 1000 times the average stress for the given section. A small applied tensile stress may, then, be expected to produce a considerable extension and thus give a quite low apparent modulus of elasticity. It is suggested that the ratio of moduli is of the same order as the strength ratio. One of the authors has observed[7] with the calcium hydrosilicate material, Microporite, at 30 lb. per cu. ft. unit weight, compressive and flexural strengths of 1300 and 260 psi., respectively, and apparent moduli of elasticity of 350,000 psi. in compression and 70,000 psi. in bending, both ratios being five. Tensile loads are taken by an elastic network. In prestressed beams, until the prestress has been neutralized, the only modulus of elasticity involved is that for compression.

The stress on the steel increases about 50 per cent as the compression in the bottom fiber is neutralized, as may readily be calculated. To make most economical use of the steel, it is suggested to apply a prestress of two-thirds of its yield point, which may be accurately and conveniently done by setting the beam in a vise and producing a definite elongation in the steel. The design loading may then be taken very safely as one-third the load required to neutralize the prestress.

After the neutralization of the compression in the bottom fiber, that part of the beam is in tension and the notable stiffness observed previously disappears.

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[7] F. O. Anderegg, "Microporite," *Rock Products*, May, 1936.

DISCUSSION

MR. THOMAS J. DOLAN[1] (*presented in written form*).—The authors have presented an interesting application of the photoelastic method of stress analysis to the problem of neutralization of the initial compressive stresses in prestressed beams.

From a theoretical consideration the 10- and 80-deg. isoclinics shown in Fig. 6 of the paper should not intersect the boundary of the model except at points of load application. Since the principal stresses developed at any free (unloaded) boundary of a member always occur on planes tangent and perpendicular to the boundary, the edges of the beam in Fig. 6 may be regarded as 0- and 90-deg. isoclinics and will not intersect any other isoclinic except at the load points. The apparent intersection of the 10- and 80-deg. isoclinics with the free boundary was probably due to the presence of initial stresses in the bakelite from which the model was made.

The writer does not believe that the apparent stiffness of prestressed beams can be accounted for on the basis of difference between tensile and compressive moduli of elasticity. For most structural materials the available data indicate that there is only a very small difference between the tensile and compressive moduli of elasticity; for concrete they are practically the same, whereas for a pottery plaster the maximum difference is about 10 per cent. Even though the prestressing places all of the material in compression, and the stress range for the lower part of the member when loading as a beam is merely one of relieving or neutralizing this compressive stress, the deflection is not governed by the initial compressive modulus of elasticity alone. Due to the curved nature of the stress-strain diagrams for most ceramic (and concrete) materials, the upper highly-stressed portion of the prestressed beam probably will have a *smaller* (tangent) modulus of elasticity accompanying the increased stresses caused by subsequent flexural loads applied to the beam than it would have if unprestressed. This decreased modulus on the compression side of the beam probably would offset any stiffness gained by increasing the modulus on the tension side of the beam by prestressing.

Adding reinforcing steel to a beam is very effective in increasing its stiffness since it adds greatly to the area of the transformed equivalent cross-section. However, unprestressed reinforcing cannot be efficiently utilized until the surrounding material is stressed in tension. This tension probably results in inelastic action consisting of microscopic cracking of the material in tension and localized slippage of the reinforcing rod; these actions are evidenced by increased deflections of the beam. The writer would like to suggest that perhaps there are two reasons for the smaller deflections that are observed when the reinforced beam is prestressed: (1) the steel becomes immediately effective in resisting moment without the development of inelastic localized readjustments in the surrounding material; (2) the steel being rigidly fastened to each end of the beam exerts gradually increasing inward forces at the ends of the beam as the flexural loads are increased, and develops negative moments similar to those produced in a restrained or fixed-ended beam. For example, a simply supported beam with a concentrated load at mid-span will deflect four times as much as one of the same span and similarly loaded but with the ends fully restrained against rotation. Without prestressing there is always a certain length of reinforcing at each end of the beam that is not fully stressed and is therefore ineffective in preventing deflection of the beam.

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[1] Assistant Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

The accompanying Fig. 1 shows a fringe photograph of a beam continuous over three supports and loaded with two equal concentrated loads *P*. By turning this beam upside down (as shown) it will be observed that the portion of this beam between the sections *A* and *B* would closely correspond with the type of fringe distribution shown on the complete beam of the authors' Figs. 3 and 4, although the relative proportions of depth to span are not the same. For this continuous beam it is a well-known fact that the deflections would be smaller than those observed in a simply supported beam, and that the end forces, *R*, would produce a bending moment at sections *A* and *B* similar to the moments applied by the springs in prestressing.

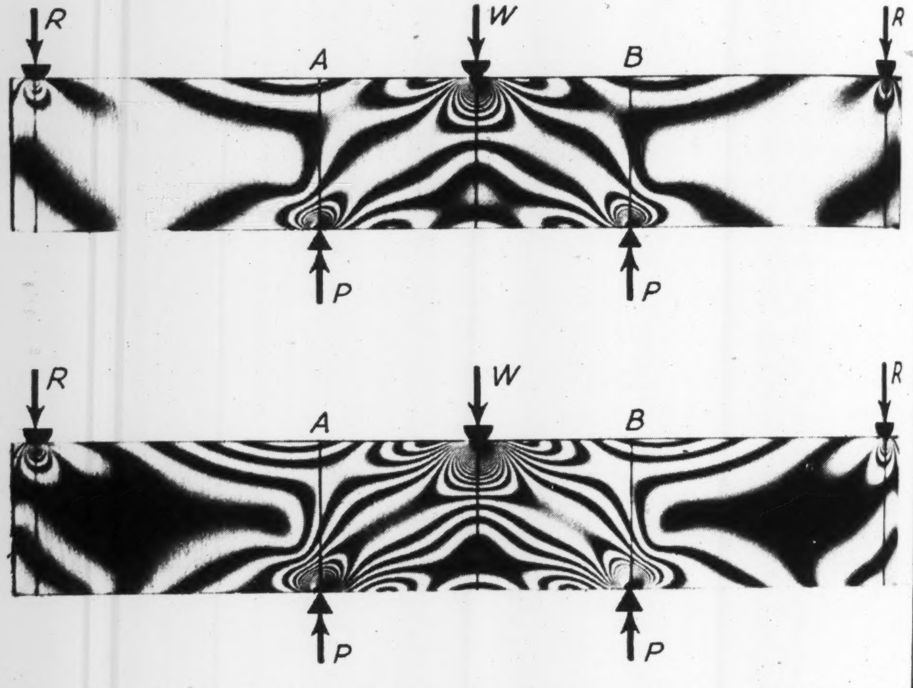

FIG. 1.—Fringe Photograph of a Beam Continuous over Three Supports and Loaded with Two Equal Concentrated Loads.

Loads *P* are 51.4 lb. on upper model and 91.4 lb. on lower model.

MR. W. K. HATT.[2]—Referring to the

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[2] Emeritus Professor of Civil Engineering, Purdue University, Lafayette, Ind.

first illustrations of the prestressed beams, was the steel separated from the concrete by destroying the bond before the steel was prestressed?

Mr. F. O. Anderegg.[3]—In that particular beam[4] the steel was covered with asphalt, but I have made beams with the steel grouted in,[5] and in that case you produce more stretch at the ends. I used a steel of a high yield point—above 100,000 psi.—and I went no higher than one-half to two-thirds of the yield point in the prestress.

Mr. Hatt.—This device for prestressing the concrete by stretching the steel has had a considerable vogue, not only abroad but in this country. I think it is a very valuable device. It has been applied not only to beams and to the floor joists, but also to hollow concrete piles, and to pipes carrying water pressure. It is interesting to know that the stresses can be determined and procure a relation between the stress in the concrete and the stress in the steel.

Mr. P. H. Bates.[6]—Mr. Hatt has called attention to the use of prestressed concrete units abroad. Some few years ago I had the pleasure of discussing this matter with Freyssinet, the French engineer whose work many of you know, particularly for his designing at that time the largest concrete arch ever erected. He is also interested in the commercial production of several types of concrete units, all of which are based upon the use of prestressing. Incidentally, while he is certain that units so designed have many possibilities, he is convinced that it is essential to use steel having a high elastic limit. The use of ordinary carbon steel accomplishes nothing in these cases.

One of his most unusual uses of prestressed concrete can be seen in the recently opened laboratory—Les Laboratoiries du Batiment et des Travaux Publics, in Paris. Here he has designed and erected a 2000 tonnes compression testing machine of prestressed concrete. This is in the form of a horizontal cylinder 14 meters long and 3.5 meters in side diameter. The high elastic limit reinforcing steel in the form of bands was highly prestressed during the placing and hardening of the concrete designed to have high compressive strengths. In use as a testing machine the inner upper side of the horizontal cylinder becomes the head of the machine and the inner lower side the lower head. Hydraulic jacks hung from the upper side apply the load to the specimen placed between the jack and the lower side. These jacks range from 100 to 2000 tonnes capacity. In this manner a very cheap precise high-capacity testing machine has been constructed.

Mr. Hatt.—We have experimented at Purdue University in the past two or three years on prestressed pipes 60 in. in diameter, whereby the hoops are prestressed, producing a stress of about 600 psi. in the barrel of the pipe. The water pressure is carried to such an extent that the initial compression stress of the concrete is not relieved. Shrinkage stresses are eliminated. Now there is just one element which ought to qualify this subject, namely, the effect of plasticity of concrete in reducing the initial compressive stress an amount depending upon the age of the concrete when prestressed.

Mr. Anderegg.—In the cases described here[4, 5] we had ceramic units and $\frac{1}{8}$-in. joints, so there was practically no shrinkage, and then after the mortar had hardened about one week we would apply a predetermined stress on the whole member.

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[3] Consulting Specialist on Building Materials, Newark, Ohio.

[4] Reproduction of Fig. 1 from article by F. O. Anderegg, "Progress in Prestressing Structural Clay Products," *Bulletin*, Am. Ceramic Soc., Vol. 18, p. 323 (1939).

[5] F. O. Anderegg and C. L. Dalzell, "Pre-Stressed Ceramic Members," *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part II, p. 447 (1935).

[6] Chief, Clay and Silicate Products Division, National Bureau of Standards, Washington, D. C.

MESSRS. F. O. ANDEREGG, ROYAL WELLER[7] AND B. FRIED[8] (*authors' closure by letter*).—Mr. Dolan is correct in stating that the 10- and 80-deg. isoclinics should not intersect the boundaries of the model and that apparent intersection is probably due to initial stresses. The significant point from this Fig. 6 is that the 20- and 70-deg. isoclinics covered the major part of the beam.

The suggestion of end restraint in aiding the stiffening of the beam is very interesting and probably explains part of the effect observed. In the photograph shown, however, there are regions of tension, while in the prestressed beam, tension (except in the steel rods) is absent. It should be emphasized that the small deflections noted are due to bending alone and are not the sums of prestressing and bending. They are appreciably less in the prestressed beam than in the absence of prestressing. It is believed that most of the notable stiffness observed is due to difference in moduli of elasticity.

A side light on the modulus of elasticity of brittle materials is obtained from some studies of silica glass fibers.[9] It was observed that the modulus increased with the strength and decreasing diameter of the flame-blown fibers. The best explanation of the diameter-strength relationship so far given is variation in number of intensity of discontinuities. As the material is pulled out discontinuities are pulled out lengthwise and have much less deleterious effect on tensile strength and also appear to reduce the stretching tendency of the fibers. Reinkober[10] has reported similar results. This idea is similar to Dolan's, ". . . inelastic action consisting of microscopic cracking . . .," but perhaps refers more to the initial stretching within discontinuities which eventuates in microscopic cracking.

When the principles of prestressing are incorporated within engineering textbooks, so that engineers acquire a better understanding of them, much wider applications will be made to our structures and machines, with reductions in weights and costs.

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[7] Instructor in Physics, The Ohio State University, Columbus, Ohio.

[8] Engineering Experiment Station, The Ohio State University, Columbus, Ohio.

[9] F. O. Anderegg, "Strength of Glass Fiber," *Industrial and Engineering Chemistry*, Vol. 31, p. 297 (1939).

[10] O. Reinkober, "Die Elastizität und Festigkeit von dünnen Quarzfäden," *Physikalische Zeitschrift*, Vol. 38, p. 112 (1937).

SONIC METHOD OF DETERMINING THE MODULUS OF ELASTICITY OF BUILDING MATERIALS UNDER PRESSURE[1]

BY LEONARD OBERT[2]

SYNOPSIS

A new sonic method of determining the modulus of elasticity of concrete, stone, and other construction materials is presented, whereby determinations can be made while the specimen is under load, as well as unloaded. The method is described and certain limitations pointed out. Results of measurements on concrete and stone are given and are compared with both static and dynamic measurements made by other investigators. The investigation indicates the sonic method described to be an accurate and relatively simple method for determining modulus of elasticity and to offer promise as a procedure for determining the stress of structural members *in situ*.

The dynamic method of determining Young's modulus of elastic materials has received increasing attention in recent years, particularly in the field of engineering and geophysics. In general, the method requires the measurement of the fundamental frequency of a rectangular prism of the material when vibrating in some particular mode of vibration. The mode of vibration excited depends on how the column is mounted and where the driving force is applied. For any particular mode of vibration, there is a simple relationship involving the frequency, dimensions, and density of the specimen from which Young's modulus can be calculated. The principal advantage of the method is its simplicity.

In the derivation of the relationships between Young's modulus and the frequency of vibration, it is assumed that the material is perfectly elastic, that is, that the stress is proportional to the strain. The amplitude of vibration and hence the strain produced in the vibrating specimen is small (less than 10^{-6} inches per inch). Thus, the region of perfect elasticity need not be particularly extensive, in fact if the stress-strain curve of the material has no abrupt variation the limit of the change in stress to the change in strain (the tangent modulus) may be used. Therefore, in calculating Young's modulus from the frequency by such a relationship, it is the tangent modulus that is obtained.

In most of the previous investigations, the specimens were not under load when the frequency of vibration was determined; hence the value obtained is the tangent modulus for a zero stress, generally designated by E_0, and commonly referred to as initial tangent modulus. With static methods this value can be determined only by extrapolation, whereas the dynamic method measures this directly. For geophysical purposes this is of some advantage because the velocity of sound in the material can be calculated for zero pressure; however, in engineering practice the value of the modulus for a given stress is of more importance.

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[1] Published by permission of the Director, U. S. Bureau of Mines.

[2] Associate Physicist, U. S. Department of the Interior, Bureau of Mines, College Park, Md.

For many materials, such as steel and glass, which possess a large region of perfect elasticity starting from zero stress, the dynamic method has been shown to be valid by many investigators. In a recent paper, Powers[3] has compared statically and dynamically determined values of E_0 for concrete and has shown that they are also in good agreement.

For stone, which in many instances is known to be more non-elastic than concrete, the static and dynamic results are more discordant. Both Zisman[4] and Ide[5] have presented evidence indicating that microscopic cracks are at least partly responsible for this disagreement.

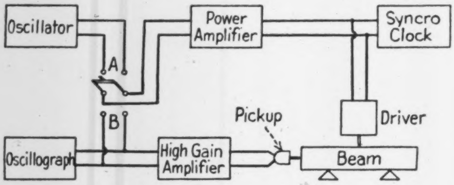

FIG. 1.—Schematic Diagram of Electrical Apparatus with Beam Mounted for the Free-Free Mode of Vibration.

The purpose of this paper is to describe a sonic method of determining Young's modulus for building materials both for zero stress and for applied pressures up to the point of failure. The results of measurements of Young's modulus on stone and concrete are presented and compared with those determined statically by others to show the validity of this method.

GENERAL CONSIDERATIONS[6]

The specimens used in the investigation were rectangular prisms, hereafter referred to as beams. Two methods of mounting the beams were employed, which are referred to as the free-free and the supported-supported mountings, and the corresponding modes of vibration and their frequencies are given the same designations.

For the free-free mode of vibration, the beam was mounted on supports located at points 0.224 L from each end, where L is the length of the beam and the driving force was applied at the center of the beam (see Fig. 1). The modulus of elasticity, E, is given by[7]

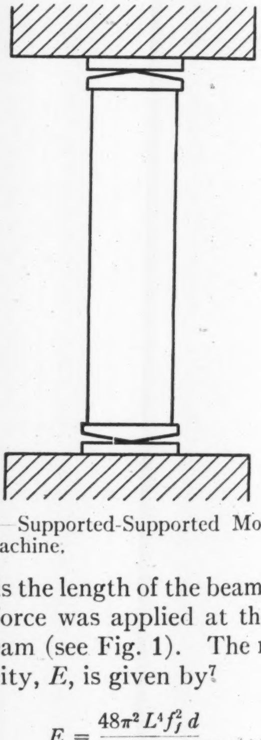

FIG. 2.—Supported-Supported Mounting in Testing Machine.

$$E = \frac{48\pi^2 L^4 f_f^2 d}{t^2 m^4} \ldots\ldots\ldots (1$$

where t = the thickness of the beam in the plane of vibration,

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[3] T. C. Powers, "Measuring Young's Modulus of Elasticity by Means of Sonic Vibrations," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 460 (1938).

[4] W. A. Zisman, "Comparison of Statically and Seismologically Determined Elastic Constants of Rock," *Proceedings*, Nat. Academy Sciences, Vol. 19, p. 680 (1933).

[5] J. M. Ide, "Comparison of Statically and Dynamically Determined Young's Modulus of Rocks," *Proceedings*, Nat. Academy Sciences, Vol. 22, p. 81 (1936).

[6] The description of this method is taken in part from a previous report. See L. Obert, "Measurement of Pressures on Rock Pillars in Underground Mines—Part I," *Report of Investigations 3444*, U. S. Bureau of Mines (1939).

[7] Lord Rayleigh, "The Theory of Sound," Second Edition, Vol. 1, pp. 242–306, The MacMillan Co., London (1926).

m = a numeric, approximately 4.73 for the fundamental,[8]

L = the length of the beam,

f_f = the free-free frequency, and

d = the density.

This is called the free-free mode of vibration because no restraints are placed on either end of the beam.

For the supported-supported mode of vibration, the beam was supported at the ends (see Fig. 2) and the driving force was applied at the middle. Young's modulus is given by[7]

$$E = \frac{48L^4 f_s^2 d}{\pi^2 t^2} \quad \text{............} (2)$$

where f_s = the supported-supported frequency.

APPARATUS

Electrical Apparatus:

The electrical apparatus served a two-fold purpose, namely, to produce a sustained vibration in the specimen and to serve as a means of determining the frequency of this vibration. A schematic diagram of the apparatus is given in Fig. 1, in which the beam is mounted for the free-free mode of vibration. With the switch in position A, the output of the beat-frequency oscillator was amplified by the power amplifier and supplied to both the General Radio Syncroclock and the driver, the device used to force the beam into sustained vibration. The vibrating beam, in turn, actuated the pickup, the output of which was amplified by a high-gain amplifier and supplied to the oscillograph.

When the frequency of the driving force is equal to the fundamental frequency of the beam, the systems are in resonance, that is, the beam vibrates with a maximum amplitude; hence the amplitude of the oscillograph pattern will have a corresponding maximum. The fundamental frequency of the beam was found by varying the frequency of ("tuning") the oscillator until a distinct maximum in the amplitude of the oscillograph pattern was obtained. When this resonance point had been tuned in, the switch was thrown to position B. The amplified pickup current was thus supplied to the power amplifier so that the system drove itself or "regenerated." In this case the beam alone stabilized the frequency of the system. The frequency of vibration was then measured with the Syncro-clock.

The pickup was made from a low-impedance phonograph pickup. The driver was made by cementing a light aluminum rod to the voice coil of a dynamic speaker. This, in turn, was fastened to the beam mechanically by a collar that previously had been cemented to the beam. The mass and electrical reactance of the driver were very small and did not affect the frequency of the beam appreciably.

For the free-free mode of vibration, the beam was mounted as previously described. The pickup was placed in contact with the end of the beam and oriented so that the pickup armature moved in the plane of vibration.

The same driver and pickup were used for the supported-supported mode of vibration. The driving force was applied at the center of the beam. The pickup also was placed in contact with the center of the beam but was oriented so that the armature moved in a plane normal to both the plane of vibration and the axis of the beam.

Testing Machine:

The beams were loaded in a Riehle universal testing machine of 100,000-lb. capacity. A ball-and-socket block was installed on the moving head of the machine to give a uniform bearing on the ends of the beams.

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[8] A small correction must be made depending on the thickness-to-length ratio. See W. P. Mason, "The Motion of a Bar Vibrating in Flexure, Including the Effects of Rotary and Lateral Inertia," *Journal*, Acoustical Soc. America, Vol. 6, p. 246 (1935).

EXPERIMENTAL PROCEDURE

The no-load modulus of elasticity was determined by measuring the fundamental frequency when the beam was mounted for the free-free mode of vibration. Young's modulus was calculated from the frequency by the use of Eq. 1. The method is perfectly straightforward, and the only errors were those made in determining the frequency, weight, and dimensions of the beam. The estimated probable error is 2 per cent, and the results could always be repeated within these limits.

Measurements of Young's modulus while the beam was under pressure (supported-supported mode) were made with the load applied through knife-edge end plates (see Fig. 2). With the driver and pickup attached as described, the frequency was measured for a series of pressures starting at 20 kg. per sq. cm. and increasing by increments of 10 to 30 kg. per sq. cm. up to the maximum load the beam would stand. The same procedure was repeated for decreasing increments to 20 kg. per sq. cm., thus completing the cycle. Two cycles were made for each of the beams, inasmuch as it was found that further cycling did not change the results.

A correction must be made when this type of mounting is used inasmuch as the end plates are part of the vibrating system (the nodal points being the points of contact of the knife edges with the moving head and platen of the testing machine). The fundamental frequency is lower than that of the beam alone, owing principally to the increase in the length of the vibrating system; however, the increase in inertia, the difference in elasticity, and possibly the discontinuity between the test specimen and the plates have some effect.

This type of mounting also introduces a possible source of error. The frequency of a beam vibrating in a flexural mode of vibration may be affected by the pressure. The frequency will be independent of the pressure only if the effect of the stiffness is large compared with that of the pressure.

It would be difficult if not impossible to calculate either the change in frequency due to the end-plate mounting or the effect of the pressure on the frequency. However, it is possible to determine the correction for the end plates and at the same time to ascertain whether or not the frequency is independent of the pressure by testing a beam of known elastic properties. For this purpose one glass and two duraluminum calibrating beams were tested. Glass and duraluminum were selected because of their good elastic properties and because they have densities approximately equal to those of stone and concrete.

The results of these calibrations show that the frequency is nearly independent of the pressure except for low pressures, for which the deviation is less than 7 per cent. These materials show no hysteresis[9] or permanent set.

To determine the frequency correction on account of the end plates and at the same time to correct deviations due to the change of frequency with pressure, the modulus of elasticity was determined for the calibrating beam by the free-free method. Then this value of the modulus was substituted in Eq. 2 and the supported-supported frequency was calculated; that is, the frequency that would be expected if there were no end-plate or pressure corrections. The difference between this value and the value of the frequency measured for any pressure gives the change in frequency attributable to the method of mounting for that pressure. The ratio of this difference in frequency to the measured frequency gives the fractional amount that the measured frequency must be raised to correct for the mounting and the pressure variation.

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[9] There is no established terminology to describe this type of curve and, for lack of more descriptive terms "hysteresis" and "permanent set" will be used to describe the area between the increasing and decreasing pressure curves and the difference between the no-load modulus before and after the pressure cycle, respectively. This is, in a sense, analogous to the usage in a stress-strain diagram.

The correction amounts to about 25 per cent, which may at first seem large; however, the additional length due to the end plates accounts for over 20 per cent of the difference, which leaves less than 5 per cent attributable to the additional inertia, difference in elasticity, and discontinuity in the media.

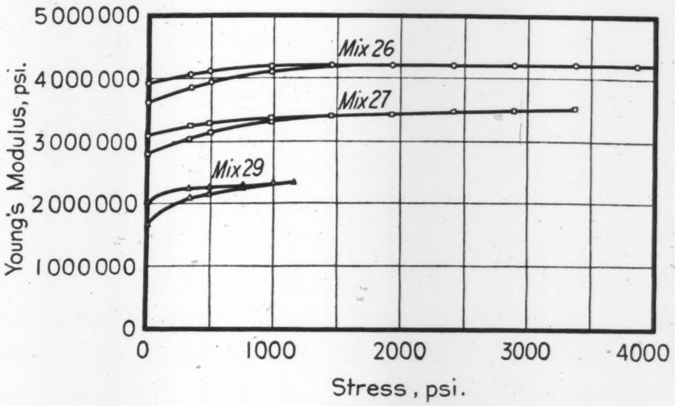

FIG. 3.—Relation Between Young's Modulus and Stress for 3 Grades of Concrete. The upper part of each curve is for the initial loading. The lower part for all subsequent loadings.

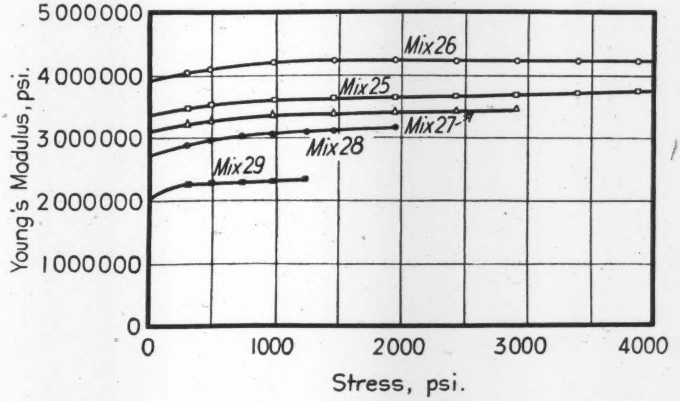

FIG. 4.—Relation Between Young's Modulus and the Stress for 5 Grades of Concrete. Curves are for the initial loading.

TEST OF CONCRETE

The tests on concrete were made in conjunction with the National Sand and Gravel Association Research Foundation in its laboratory at the University of Maryland. A series of five different mixes of concrete, determined by the ratio of the cement to total aggregate, were studied. Three batches were made from each mix on three different days, and three $3\frac{1}{2}$ by 3 by $13\frac{3}{4}$-in. beams and one 6 by 12-in. cylinder were made from each batch. This made a total of 15 cylinders and 45 beams. Of the latter, 15 were tested and the rest saved for future reference.

The sand was used graded as received and had a fineness modulus of approximately 2.94. The gravel was separated into two sizes, No. 4 to $\frac{3}{8}$ in. and $\frac{3}{8}$ to $\frac{3}{4}$ in., and recombined to have a fineness modulus of 6.60. The mixed aggregate consisted of 67 per cent sand and 43 per cent gravel and had a fineness modulus of 4.50.

The beams were cured 28 days in water and 28 days in air and then dried out for 24 hr. in an oven. Leadite (a sulfur-clay compound) capping was used to give a good bearing surface.

TABLE I.—TEST OF CONCRETE.

Reference Number	Mix, cement to aggregate	Water-Cement Ratio, by weight	Slump, in.	E_0, psi. $\times 10^6$	E_1, psi. $\times 10^6$	$K = \frac{(E_1 - E_0)}{(E_0)} 100$
25....	1:1	0.31	3¼	3.36	3.65	8.2
26....	1:3	0.42	2	3.93	4.20	7.4
27....	1:5	0.55	2	3.12	3.38	8.0
28 ...	1:7	0.80	2	2.72	3.00	9.4
29....	1:9	1.20	1¾	2.01	2.26	13.0

Figure 3 gives representative Young's modulus-stress curves for three beams from different mixes. In all instances the upper part of each curve is for the initial loading and the lower curve for all further loading, both increasing and decreasing. The difference between the initial no-load modulus and that obtained after cycling is a measure of the permanent set. Figure 4 gives the initial load curves for the five mixes, each curve being an average for three beams. The curves are all similar in that they show that the modulus of elasticity increases with the stress asymptotically approaching a constant value, the increase being more rapid for relatively low pressures. The richer mixes of concrete show less change than the leaner grades; for example, the 1:3 mix shows an increase in Young's modulus of 7.4 per cent between zero stress and a stress one-quarter that of the ultimate strength, whereas the 1:9 mix shows a corresponding increase of 13 per cent. This is in contradistinction to the results determined by the static method, where Young's modulus, calculated from the slope of the stress-strain curve, is nearly constant for low loads and decreases for higher loads. Furthermore, the static method shows that the modulus for leaner grades of concretes decreases more rapidly, hence, for these concretes the divergence between the two methods is greater. As yet, no explanation for the differences between these two methods has been found.

The values of the no-load moduli are in good agreement with accepted values,[10] increasing from 2.0×10^6 to 4.0×10^6 psi. as the richness of the mixtures increase.

A summary of the results of the concrete tests is given in Table I. The compressive strengths were determined from the 6 by 12-in. cylinders which were cured in the same manner as the beams except that they were not oven dried. E_0 is the tangent modulus for zero stress determined from the free-free frequency and E_1 is the tangent modulus calculated from the supported-supported frequency for a stress one-quarter of the ultimate strength—that stress being selected as approximating commonly used working stresses. K is the percentage change in the modulus between zero stress and a stress one-fourth of the ultimate strength, that is,

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[10] For example see Stanton Walker, "Modulus of Elasticity of Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. XIX, Part II, p. 510 (1919); T. C. Powers, "Measuring Young's Modulus of Elasticity by Means of Sonic Vibrations," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 460 (1938); J. B. Johnson, "Materials of Construction," Seventh Edition, John Wiley and Sons, New York City (1930).

$$K = \frac{(E_1 - E_0)}{(E_0)} 100$$

The results show that the no-load determination of the modulus is not a bad approximation to the loaded value, particularly for normal mixes of concrete.

TEST OF BUILDING STONE

The stone beams were sawed from common building stone without major defects, in the form of rectangular prisms 3 by $3\frac{1}{2}$ by 14 in. After cutting, the samples were allowed to stand at room temperature for at least two weeks. Three pieces of each sample were cut, two of which were used for testing while the third was kept for a reference sample. For sedimentary rocks, one set of samples was cut parallel and another perpendicular to the bedding plane. The ends of the beams were capped with Leadite. The density was determined by dividing the weight by the measured volume.

Figure 5 gives the Young's modulus-stress curves for four types of stone, namely, sandstone, limestone, marble, and granite. The upper part of the curve is in all instances for the initial loading, the lower curve is for all subsequent loadings.

The results on stone show that with the exception of limestone, the modulus of elasticity increases rapidly in the region of low pressures asymptotically approaching a constant. This is similar to the behavior of the concrete beams except that the change is much larger. Sandstone shows an increase in Young's modulus of over 100 per cent between zero stress and a stress one-quarter of the ultimate strength. These results are in good agreement with those of other investigators,[11] both as to the magnitude and change of the modulus, for example, in the report of the Watertown Arsenal on granite from Pigeon Hill, Mass. the modulus of elasticity calculated from the slope of the stress-strain curve is shown to increase from 6.06×10^6 psi. at zero stress to 9.0×10^6 psi. for a stress of 5000 psi. The results

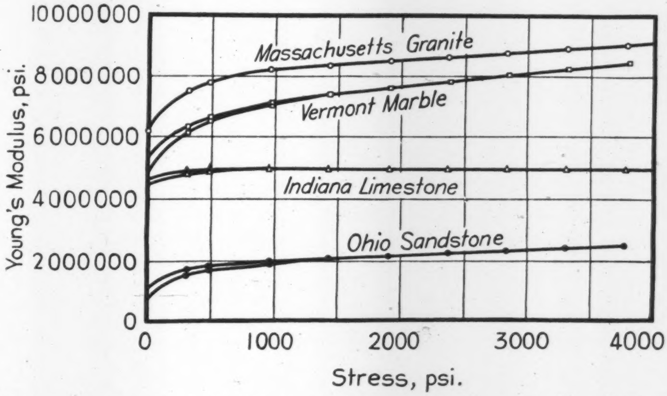

FIG. 5.—Relation Between Young's Modulus and Stress for Four Building Stones. The upper part of each curve is for the initial loading, the lower part for all subsequent loadings.

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[11] F. D. Adams and E. G. Coker, "An Investigation into the Elastic Constants of Rocks," *Publication 46*, Carnegie Institution of Washington, 69 pp. (1906); L. H. Adams and R. E. Gibson, "The Elastic Properties of Certain Basic Rocks and of Their Constituent Minerals," *Proceedings*, Nat. Academy Sciences, Vol. 15, p. 713 (1929); "Test of Metals," Watertown Arsenal (1894, 1895 and 1905); W. A. Zisman, "Comparison of Statically and Seismologically Determined Elastic Constants of Rocks," *Proceedings*, Nat. Academy Sciences, Vol. 19, p. 680 (1933).

of this investigation on a similar granite show that the modulus increases from 6.30×10^6 to 9.15×10^6 psi. for an increasing pressure interval. Comparison of results on Kibbee sandstone is also in similar agreement. The no-load modulus of Rockport and Quincy granite is also in good agreement with the sonic measurements made by Ide.[5] Table II gives the tabulation of the results on stone. The results show that the value of the no-load modulus is in most instances a poor approximation to the value of the modulus at a stress equal to one-fourth of the ultimate strength.

TABLE II.—TEST OF BUILDING STONE.

Material	Reference Number	Direction of Bedding Plane	Density, lb. per cu.ft.	E_0, psi. $\times 10^6$	E_1, psi. $\times 10^6$	$K = \frac{(E_1 - E_0)}{(E_0)} 100$	Crushing Strength, psi.[a]
Limestone, Bedford, Ind.	21	Perpendicular to axis	139	4.16	4.36	5.0	10 000
	24	Parallel to axis	146	5.12	5.85	14.2	
Marble, Danby, Vt.	27	Parallel to axis	168	9.05	9.60	6.0	13 600
	30	Perpendicular to axis	168	5.80	8.31	43.5	
Marble, Cockeysville, Md.	33	....	178	9.65	11.0	14.0	22 400
Sandstone, Briar Hill, Ohio	36	Perpendicular to axis	127	1.08	2.20	104	10 300
	39	Parallel to axis	126	1.13	2.22	97	
Sandstone, Kibbee, Mass.	42	Perpendicular to axis	140	1.65	2.76	65.5	10 000
	45	Parallel to axis	138	1.64	2.60	59.5	
Granite, Quincy, Mass.	48	....	165	6.30	9.00	30.0	17 700
Granite, Rockport, Mass.	51	....	163	5.60	8.31	48.5	18 500

[a] Taken from handbooks and the results of other investigators.

CONCLUSION

The dynamic method of determining the tangent modulus of elasticity of building materials, described in this paper, has been found to be accurate, yet relatively simple, both for zero stress and for applied stresses up to the point of failure. After the apparatus is once calibrated, a determination of the elastic properties of the given specimen can be made in a period of about one hour to an accuracy of approximately 2 per cent.

The measurements on stone show that this method gives the value of the no-load modulus in good agreement with both static and sonic determinations made by other investigators, and that the Young's modulus-stress curves are also in good agreement with similar curves calculated from statically determined stress-strain measurements. The results on stone show, however, that the no-load modulus of elasticity is not a good approximation to the modulus determined under load, the difference amounting to as much as 100 per cent for a stress of one-fourth the ultimate strength. For concrete the no-load moduli determined by this method compare favorably with accepted values. The results also show that the no-load modulus is a fair approximation to the modulus under load, the difference being 10 per cent or less for normal grades of concrete stressed to one-fourth of their ultimate stress. However, the variation of the modulus with stress shows a divergence from measurements made by the static method, this divergence being from 7 to 15 per cent, depending upon the grade of concrete.

In order that a better comparison between the results of various investigators can be made, it is suggested that a standard routine be accepted for testing building materials by sonic methods. It was found that the best results on concrete were obtained when the sample was cured 28 days in water, 28 days in air, and then dried out for 24 hr. in an oven, the last step being absolutely essential. For stone, it was found that drying the samples at room temperature for two weeks was sufficient to give consistent results.

This investigation is part of a comprehensive program to determine a method of measuring the load on stone and concrete supports, *in situ*. The method requires a knowledge of the variation of Young's modulus with stress for the material concerned. From a measurement of the modulus of elasticity of the support, the pressure can then be determined.

Acknowledgments:

The author is deeply indebted to the National Bureau of Standards for casting the glass calibrating column and to the University of Maryland for the generous loan of its laboratory facilities, including the mechanical press. The author is further indebted to C. H. Shaw of Johns Hopkins University for many valuable discussions.

DISCUSSION

Mr. F. B. Hornibrook[1] (*presented in written form*).—The author has made a valuable contribution to the usefulness of the sonic method for measuring Young's modulus of elasticity of concrete by his determination of the relation between the no-load modulus and the modulus under load.

The shapes of the curves in Figs. 3 and 4 of the paper indicate that the corresponding stress-strain curves, with the probable exception of the curve for Mix 26, would be continuously concave upwards. This, as the author points out, is contrary to statically determined stress-strain relationships for concrete.

In the determination of the elastic properties of concrete by the static method, however, it is very difficult, if not impossible, to separate completely the plastic deformation from the elastic deformation. Is it not possible that in the sonic method this separation is effected?

In measurements, notably by Glanville,[2] and by Jones and Richart,[3] of Young's modulus by the static method, in which attempts were made to avoid the effects of plastic deformation, considerable evidence was obtained to indicate that a straight-line stress-strain relationship exists at moderate stresses for normal concrete. Glanville after careful measurements at different rates of loading, extrapolated the data to give a stress-strain plot for an imagined instantaneous loading. He obtained a straight-line graph for this instantaneous loading in all cases except for very lean concrete, in which he found the creep so rapid that it was extremely difficult to observe the initial portion of the curve.

Jones and Richart, using telemeter gages in conjunction with an oscillograph recorder, also studied the effects of rates of loading and were able to impose a full load on 7-day specimens in as short a time as 1 sec. They state that they found that the variation in secant modulus of elasticity with testing speed was at least qualitatively in agreement with the results of Glanville's experiments.

Thus, the greater divergence between the static and sonic results found by the author for the lean mixes is in part, at least, explained by Glanville's findings with respect to the very rapid creep in lean concrete under static load.

In the sonic method the load is applied in considerably less than 0.01 sec. and the deformation being less than 0.000001 in. per inch, it may be that the results approximate the theoretical elastic properties of the concrete as dissociated from the plastic properties.

The author's suggestion that a standard routine be accepted for the testing of building materials by the sonic method is well taken, inasmuch as it appears that the method can be used to good advantage for several types of tests.

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[1] Associate Materials Engineer, National Bureau of Standards, Washington, D. C.

[2] W. H. Glanville, "Creep or Flow of Concrete Under Load," *Building Research Technical Paper No. 12*, p. 6 (1930).

[3] Paul G. Jones and F. E. Richart, "The Effect of Testing Speed on Strength and Elastic Properties of Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part II, p. 380 (1936).

Thus, besides the author's comprehensive program, such studies as the relation of Young's modulus to the degree of disintegration produced in freezing and thawing, wetting and drying, or heating and cooling of concrete or the weathering properties of field concrete as indicated by changes in modulus of elasticity could all be well studied by the sonic method. However, to make the method generally applicable it would seem desirable to be able to test specimens in saturated or partially saturated conditions as well as in the oven-dried condition as is done by the author.

Tests made recently at the National Bureau of Standards by the sonic method on 4 by 16-in. concrete cylinders indicate that there is a difference in the modulus of elasticity between saturated specimens and dry specimens which is several times that attributable to the change in density, the modulus being greater for the wet specimens. It was also noted that the sonic modulus is much more sensitive to small moisture changes in a relatively dry specimen than in a relatively wet specimen.

MR. LEONARD OBERT.[4]—The sonic method of determining Young's modulus of elasticity always gives the ratio of the stress to the elastic strain; however, the plastic deformation indirectly alters the elastic properties of the material, hence the two are not entirely separable.

It must be pointed out that for engineering purposes the total deformation per unit stress is of more value than the elastic strain alone, hence the sonic method cannot replace the static method of measurement when the total deformation must be accurately known. However, the divergence between the static and the sonic measurements is small (less than 15 per cent for concrete).

MR. W. K. HATT.[5]—I should like to ask whether in those cases where the concrete was under compression, there was any difference in the modulus of elasticity of those same pieces of concrete in tension.

MR. OBERT.—No measurements have been made on the specimens under tension; in fact no sonic method has been devised as yet for making such determinations.

MR. C. H. SCHOLER.[6]—I was much interested in your comments on measuring these changes by measuring the velocity of sound. Have you developed a portable device that could be moved about in mines?

MR. OBERT.—We have developed a portable apparatus for making such measurements, and in preliminary tests we have measured the modulus of elasticity in rock pillars *in situ*. With this apparatus the velocity is measured directly.

[AUTHOR'S NOTE.—Satisfactory measurements have been made in both rock and concrete columns *in situ*. A Bureau of Mines Report of Investigations is in progress describing the apparatus and tests.]

MR. SCHOLER.—Does the direction of the frontal sound wave, whether or not it is vertical, make any difference?

MR. OBERT.—The sound wave should be a plane wave traveling in a direction normal to the line of measurement. This condition is very nearly realized in a column in which the length to diameter ratio is large.

MR. SCHOLER.—I was thinking of its application to concrete in connection with studies of disintegration of the material. Could this method be used to determine the extent of deterioration that had occurred?

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[4] Associate Physicist, U. S. Department of the Interior, Bureau of Mines, College Park, Md.

[5] Emeritus Professor of Civil Engineering, Purdue University, Lafayette, Ind.

[6] Consulting Engineer, Portland Cement Assn., Binghamton, N. Y. On leave from Kansas State College for research work with the Portland Cement Assn.

MR. OBERT.—I believe the method would prove very satisfactory for such measurements.

[AUTHOR'S NOTE.—See paper by Floyd B. Hornibrook, "Application of Sonic Method to Freezing and Thawing Studies of Concrete," ASTM BULLETIN, No. 101, December 1939, p. 5.]

MR. SCHOLER.—I should like to ask whether you have tried to measure the velocity of sound on a concrete pavement or concrete abutment? Mr. Thomson of our staff at Kansas State College has been trying to measure the velocity of sound through small distances of perhaps 12 in. or some small multiple of this distance. Could determinations be made on such small values?

MR. OBERT.—The ultimate object of our investigation is to make velocity measurements on rock or concrete mine pillars; however, the method could be applied to any concrete structure. We have found that the minimum distance required to make satisfactory measurements is about 10 ft.

MR. SCHOLER.—In measuring the deterioration of concrete by sonic vibrations we get the change in frequency of a member as the actual value of measurement. I am anxious to know what the possibilities are for using the velocity of sound to check up on the same type of deterioration?

MR. OBERT.—The frequency is actually the quantity measured in all small specimen tests of this type. The velocity of sound is directly calculated from the frequency by a simple relationship which depends on the particular mode of vibration set up in the sample. This relationship also includes the dimensions of the sample. The advantage in quoting the velocity rather than the frequency is that the velocity is independent of the size of the specimen.

SYMPOSIUM ON SHEAR TESTING OF SOILS

TORSION SHEAR TESTS AND THEIR PLACE IN THE DETERMINATION OF THE SHEARING RESISTANCE OF SOILS

By M. Juul Hvorslev[1]

The object of this paper is to give a review of the various apparatus which have been developed for torsion shear tests and to discuss the practical advantages and disadvantages and the sources of error in the results obtained by this type of test as compared with other types of shear tests. For this purpose a brief review of other commonly used types of shear tests will also be given. Examples of results of torsion shear tests and the theory for determination of shearing stresses and strains from observed torsional moments and corresponding twists are given in two appendices.

The suitability of a certain type of shear test is determined by its ability to furnish the results which constitute the principal objects of the shear tests. These principal objects are the determination of:

1. The maximum shearing resistance, that is, the shearing stress at which failure or rapid plastic flow starts. The maximum shearing resistance generally forms the basis for the computation of the factor of safety against failure of the soil itself.

2. The bond resistance (Terzaghi (**14**)[2]) and the velocity of the slow plastic flow before failure. Many cohesive soils are probably subject to such a flow, see Fig. 10, which may affect the settlements and displacements and thereby the safety of a superimposed structure.

3. The temporary or permanent decrease of the shearing resistance after failure. Most soils are subject to a decrease of the shearing resistance after failure and its ultimate minimum value may in some cases be as low as 20 per cent of the maximum value of the shearing resistance, see Appendix I.[3] The fact that very large displacements often are required to produce this minimum value of the shearing resistance seriously affects the suitability of various types of shearing apparatus. The data on the decrease of the shearing resistance after failure are required to determine the factor of safety of earth structures in which a localized failure of the soil is allowed or cannot be prevented.

4. The stress-strain relationships and volume change characteristics due to shearing stresses. These data are required for the determination of the critical void ratio of the soil and the lateral and vertical displacements of structures built of or on the soil. They are also of great importance in the interpretation and application of the other results of the shear tests.

Besides the ability of a particular shear test to furnish the above-mentioned data, the simplicity of the construction and operation of the testing apparatus, the difficulties in preparation of test specimens, and the time required for performance of the tests must also be taken into consideration.

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[1] Research Engineer, Pierce Hall, Harvard University, Cambridge, Mass.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 1021.

[3] See p. 1013.

A description of the ring shearing apparatus shown in Fig. 6 and the stress-strain theory presented in Appendix II[4] has been published in a paper written in German (7). An abstract of the preliminary draft of this paper was submitted to the International Conference on Soil Mechanics and Foundation Engineering in 1936 (6). However, a complete description of the apparatus and its theory has not been published before in English.

TRANSLATORY SHEAR TESTS

In the translatory or simple, direct shear test the stress condition induced by the shearing load approaches a state of simple shear and is produced by a translatory movement of one part of the shearing box, while the other part is held in a fixed position. Several materially different types of translatory shearing apparatus have been developed, the most commonly used and probably also the best being the apparatus developed by Krey and later improved by Terzaghi and Casagrande. A diagrammatic drawing of such a shearing apparatus is shown in Fig. 1. The shearing load S causes a unilateral movement of the upper frame while the lower frame is held in a fixed position. In other apparatus of the Krey type the upper frame is held in a fixed position while the lower frame is moved, but there is no material difference in the stress conditions and principal sources of error thus produced.

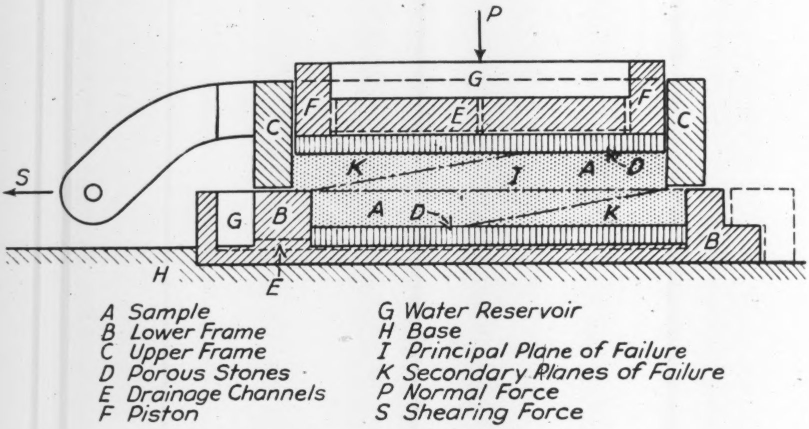

FIG. 1.—Typical Translatory Shearing Apparatus.

The principal advantages of this type of apparatus are that it is simple in construction and operation and it is comparatively easy to prepare the test specimens. Furthermore, the excellent drainage facilities allow "slow shear tests" to be completed in a relatively short period of time.

The disadvantages are the decrease of the effective cross-section of the sample during the test and a rather complicated stress condition which causes progressive failure to start during the early stages of the test; depending on the decrease of the shearing resistance after failure, this may seriously affect the test results. In the case of samples of undisturbed soil, it is often difficult to transmit the shearing load to the sample without causing disturbance of the soil and, in the case of small, vertical, normal loads, the upper frame will often "ride" over the sample and thereby make the results of the test entirely unreliable. The lateral displacements of the upper frame and the vertical movements of the piston do not directly indicate the unit strains and volume changes of the soil in the zone of failure (7, 13).

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[4] See p. 1017.

Corrections can be made for some of these sources of error and approximately correct values for the maximum shearing resistance obtained in tests with remolded cohesive soils but not in tests with undisturbed soils, which are subject to a material and rapid decrease of the shearing resistance upon partial disturbance or failure. Due to the decrease of the effective cross-section of the sample during the test, the apparatus is not suited for the determination of the decrease of the shearing resistance after failure and is suited to a limited extent only for the investigation of the slow plastic flow before failure.

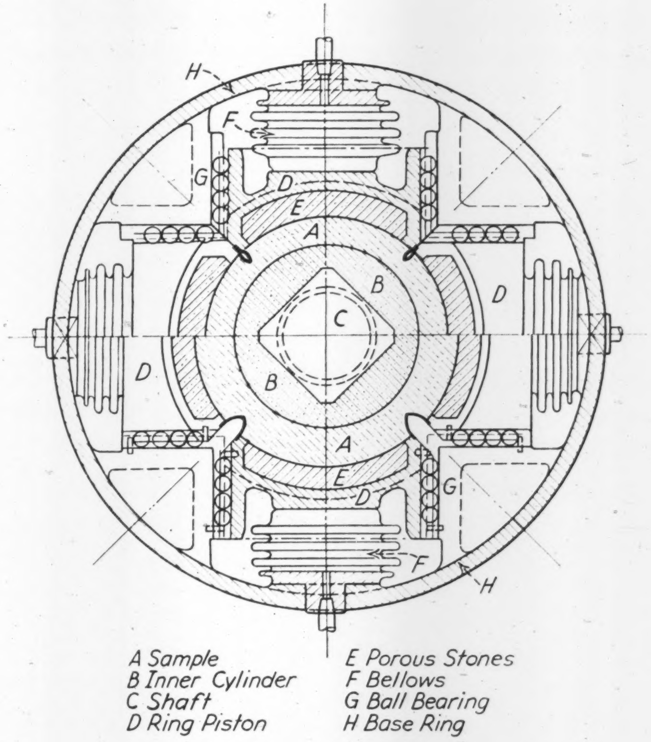


FIG. 2.—Rotary Shearing Apparatus.
By A. Casagrande and U. S. Engineer Office, Boston, Mass.

ROTARY SHEARING APPARATUS

The rotary shearing apparatus is another type of direct shearing apparatus. The sample has the form of a hollow cylinder and is confined between two cover plates and an inner and outer cylinder, one of which is rotated. The normal external load is radial and is transmitted through one of the cylinders, which is divided into segments in such a manner that it can follow the changes in wall thickness of the sample during consolidation. The sample is not subjected to torsion but rather to simple shear as in the translatory shearing apparatus.

During a visit in 1933 to the Preussischen Versuchsanstalt für Wasser-, Erd- und Schiffbau in Berlin, the author was shown a model of a rotary shearing apparatus. This particular apparatus, however, has been abandoned as impractical because of difficulties in transmitting and measuring the radial normal forces. Another rotary shearing apparatus was designed independently by A. Casagrande in collaboration with the Boston District of the U. S. Corps of Engineers. The principles of this apparatus are shown in Fig 2. The cylindrical sample, *A*, has a height of $2\frac{1}{2}$ in. and an internal diameter of $2\frac{3}{4}$ in., and an external diameter which varies with the consolidation of the sample. The inner cylinder, *B*, is a porous stone which is provided with a square hole for the shaft, *C*, by means of which is is rotated. The four pistons, *D*, form the outer cylinder; they are guided by the ball bearings, *G*, and the brackets of the stationary base ring, *H*, and cannot rotate. The pistons are forced against the sample by hydrostatic pressure, exerted through the bellows, *F*; all four bellows are connected to the same pressure tank. The upper end of the sample is covered by a plate which is attached to the shaft, *C*, while the lower end of the cylinder rests against the stationary base of the apparatus.

The principal advantages of the rotary shearing apparatus are that the shearing stresses are much more uniformly distributed than in the translatory shearing apparatus and that the cross-section of the sample does not change materially during the test. The sample can, therefore, be subjected to any desired shear displacement and the apparatus is well suited for investigation of the decrease of the shearing resistance after failure.

The principal disadvantages are the complicated construction of the apparatus and the difficulties in preparation and placement of undisturbed cylindrical samples and in transmission of the shearing load thereto without causing disturbance of the soil structure. The apparatus is, therefore, primarily suited for tests on remolded soils.

TRIAXIAL SHEAR TESTS

In the triaxial shear or compression tests a cylindrical sample is subjected to definitely known external vertical and horizontal normal pressures. The shearing resistance is not determined directly, as in the translatory shearing test, but is obtained from corresponding values of the vertical and horizontal normal pressures at failure and Mohr's circles of stress. The external pressures are exerted in part by a pressure fluid and in part by a piston, Fig. 3. The cylindrical surface of the sample is protected against contact with the pressure fluid by means

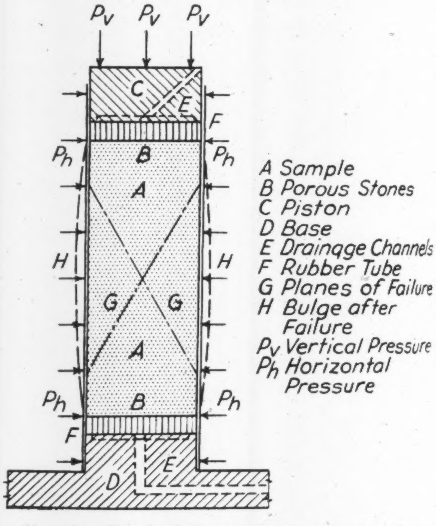


FIG. 3.—Typical Triaxial Compression Tests.

of a rubber membrane, while the ends of the sample are in contact with porous stones, through which drainage can take place. Attempts to accelerate the drainage have been made by placing vertical strips of filter paper between the rubber membrane and the sample or by providing the sample with a small core, composed of a mixture of sand and mica (Rendulic (11)). Neither of these methods is entirely satisfactory. Filter paper compresses during the test and it is difficult to apply the second method to undisturbed samples without causing a partial disturbance of the soil; furthermore, the correct proportioning of the sand and mica mixture requires advance knowledge of the elastic and consolidation characteristics of the particular soil which is to be tested.

The advantages of this type of test are that the external test loads are applied as normal forces which can be transmitted to the sample without causing disturbance of the soil structure. In contrast to translatory, rotary, and torsion shear tests, the vertical and horizontal external loads can be varied independently of each other and this renders the test much more flexible than other tests and allows a closer approximation in the laboratory of the actual stress conditions in the foundation or earth structure. Furthermore, for stress conditions which are not close to those causing failure, the stresses and deformations are fairly uniformly distributed over that part of the sample in which failure ultimately occurs. The construction of the apparatus permits accurate measurement of the amounts of water expelled or absorbed by the sample during the tests and thereby a satisfactory direct determination of the volume changes during the greater part of the test.

The principal disadvantages are that long samples are required to obtain a uniform distribution of the stresses in the zones of failure, that satisfactory methods for drainage through the cylindrical surface of the sample have not yet been developed, and that large and irregular changes in cross-section take place just before and after failure. This causes a non-uniform distribution of the stresses and makes it difficult to determine the changes in void ratio and the decrease of the shearing resistance after failure.

At the present stage of development of soil testing apparatus the triaxial shear test seems to offer the best method for determination of the maximum shearing resistance and the stress-strain relationships and volume changes before failure of undisturbed soils, temporarily excepting "slow tests" on soils of low permeability. The triaxial shear test is also suited for the investigation of the slow plastic flow before failure but not for the determination of the decrease of the shearing resistance after failure.

When the results of triaxial compression tests are to be compared with the results of translatory and torsion shear tests, it should be remembered that a direct comparison requires comparable stress conditions at failure and identical orientation of the planes of stratification with respect to the planes of failure. In translatory and torsion shear tests the sample is confined during the process of consolidation and the stress condition imposed during the actual test approaches that of pure shear. At the start of a comparative triaxial compression test the ratio of the horizontal to the vertical external pressure should therefore be the same as in the above-mentioned tests, and during the test the horizontal pressure should be decreased by an amount equal to the increase in the vertical pressure—pure shear. Practically all soils are stratified, even after remolding and reconsolida-

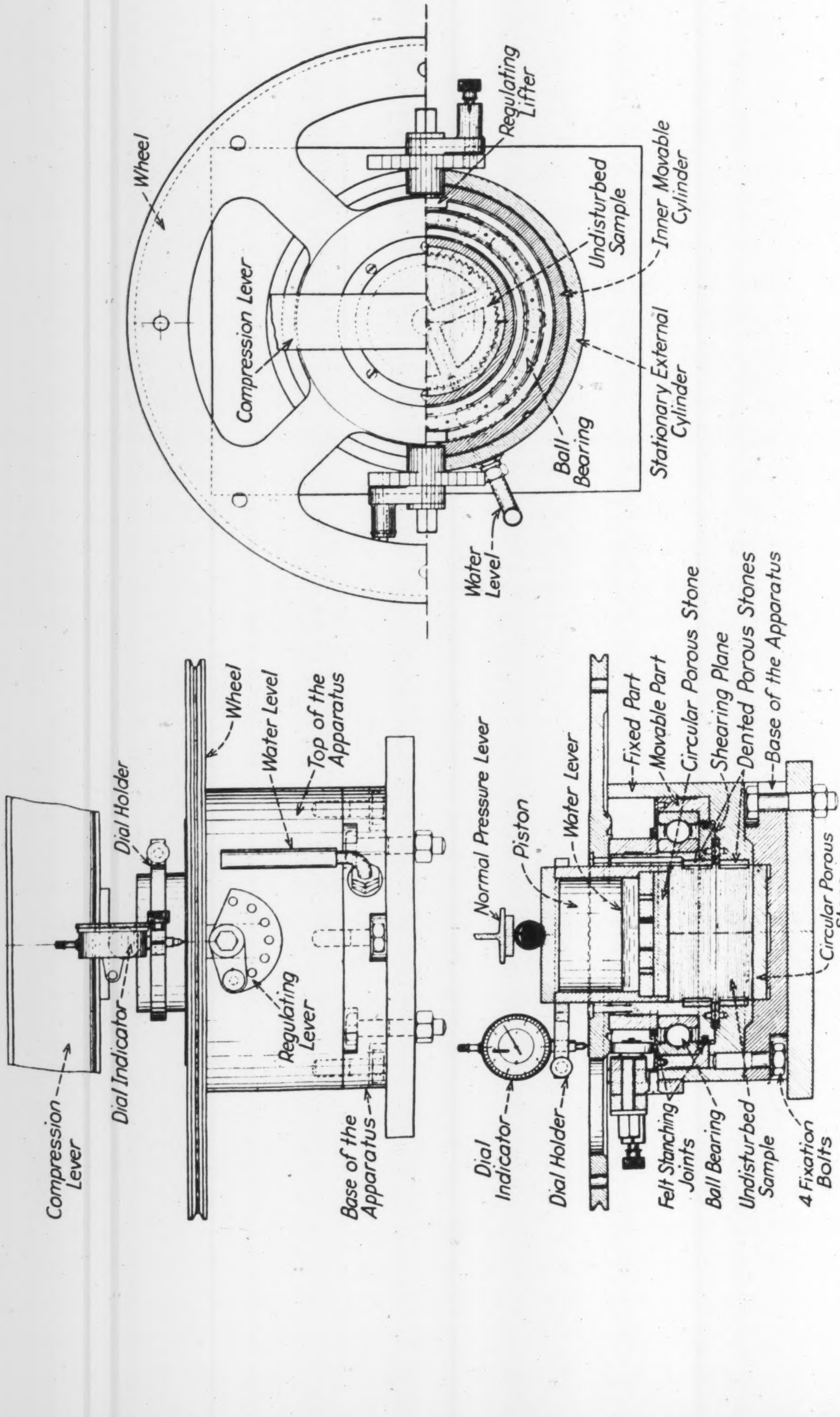

Wheel
Regulating Lifter
Undisturbed Sample
Inner Movable Cylinder
Compression Lever
Stationary External Cylinder
Ball Bearing
Water Level
Compression Lever
Dial Indicator
Dial Holder
Wheel
Water Level
Top of the Apparatus
Regulating Lever
Base of the Apparatus
Normal Pressure Lever
Piston
Water Lever
Fixed Part
Movable Part
Circular Porous Stone
Shearing Plane
Dented Porous Stones
Base of the Apparatus
Circular Porous Stone
Dial Indicator
Dial Holder
Felt Stanching Joints
Ball Bearing
Undisturbed Sample
4 Fixation Bolts

Fig. 4.—Torsion Shearing Apparatus with a Solid Cylindrical Test Specimen.
By C. Langer.

tion, and in the translatory and torsion shear tests the planes of stratification are generally parallel to the planes of failure. The samples for comparative triaxial compression tests should, therefore, be prepared in such a manner that the planes of stratification make an angle of approximately $45 - \frac{\phi}{2}$ deg. with the axis of the sample.

TORSION SHEAR TESTS ON SOLID CYLINDRICAL TEST SPECIMENS

Torsion shear tests are made on cylindrical samples with either a solid or ring-shaped cross-section. In both cases the principal advantage of this type of test is that the cross-section of the sample does not change during the tests and that any desired angular displacement can be produced.

To the author's knowledge, the first torsion shear apparatus for soils was developed in 1916 by the A.S.C.E. Special Committee to Codify Present Practice on the Bearing Value of Soils for Foundations (1). It consists of a cylindrical container and a piston through which a vertical normal load is applied to the sample. In a recess in the bottom of the cylinder is a disk which can be rotated by means of a lever under the cylinder. The disk rests on ball bearings and is furnished with radial ribs to engage the soil. Since the disk has a diameter of only one-half that of the cylinder there is danger that the soil will "arch over" and it is difficult to determine the actual normal stress on the plane of failure. A similar apparatus, but one having a combined piston and rotating disk, was developed by the Institute of Technology in Hanover, Germany. (Franzius (3), Streck (12)). In both types of apparatus the failure occurs close to the ribs in the rotating disk and this will, in case of tests with soils which are subject to decrease in shearing resistance upon partial disturbance, cause a decrease in the observed shearing resistance.

Another apparatus, in which a soil sample of solid circular cross-section is subjected to torsion, has recently been developed by Langer (8, 9), and is shown in Fig. 4. The sample has a diameter of 10.0 cm. and a height of 6 cm. and is confined between two porous stones and an upper and lower ring. The lower ring is fastened to a base and thereby held stationary, while the upper ring is movable, is guided by ball bearings and fastened to a wheel through which the torsion load is applied. The torsion load is transmitted to the sample by means of dentated porous stones in the walls of the rings. The upper ring is raised slightly by means of a "regulating lifter" before the start of the actual shearing test in order to eliminate friction between the two rings and to assure transmission of the total vertical load to the plane of failure. The vertical load is applied through a lever, a steel ball and a hollow piston, which also serves as a water reservoir. A second water reservoir is provided by a glass standpipe which is connected to the lower porous stone.

A similar torsion shear apparatus but without some of the refinements of the Langer apparatus has been developed independently by W. W. Johnson, Engineer on Special Assignment, State Highway Commission of Kansas.

As mentioned above, the principal advantage of this type of apparatus is that the cross-section of the sample does not change during the test and that any desired displacement can be obtained. The apparatus is, therefore, suited for investigation of the variations of the shearing resistance after failure. Furthermore, the sample is comparatively easy to prepare, it is short and there are ample drainage facilities.

In torsion shear tests on solid cylindrical samples, the shearing stresses and strains vary from zero at the center to a maximum at the outer surface of the sample. This distribution of stresses and strains does not seriously affect their determination if the methods outlined in Appendix II are used but it makes this type of test unsuitable for investigation of the slow plastic flow before failure. Furthermore, since soils may undergo considerable volume changes when subjected to pure shear, the unit volume changes will also increase from the center to the surface, and, since the piston is rigid, thereby cause a nonuniform and unknown distribution of the vertical normal stresses on the plane of failure. This tendency to a nonuniform distribution of the vertical normal stresses will to some extent be counteracted by a plastic flow of the soil in a radial direction. Furthermore, these variations in stresses and volume changes make it difficult to correlate the observed vertical movements of the piston with the stresses and volume changes in the zone of failure.

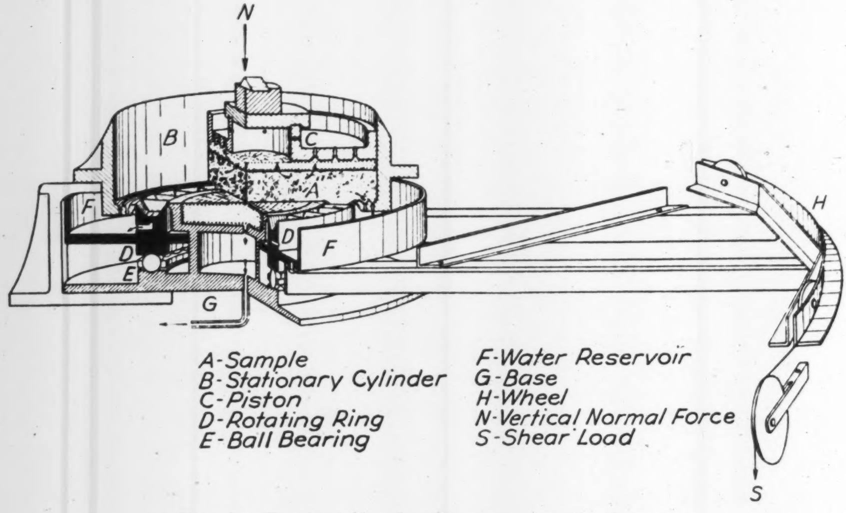


FIG. 5.—Torsion Shearing Apparatus by Tiedemann.
Die Bautechnik, Nos. 30 and 33 (1937).

The horizontal, external, normal pressure exerted by the rings cannot be controlled or definitely determined. The raising of the upper ring will eliminate normal and friction forces between the rings, but it will also create a zone of weakness along the exposed surface of the sample, and there is always danger that soft soil will be squeezed out into the narrow space between the rings and thereby re-establish friction and increase the settlement of the piston. Finally, a concentration of the shearing stresses will take place in the soil close to the edges of the rings and may exert considerable influence on the test results because of its large moment arm. The disadvantages and sources of error mentioned in this paragraph apply also to translatory shear tests and torsion shear tests on ring-shaped samples.

The teeth of the porous stones in the apparatus shown in Fig. 4 will, in case of tests on undisturbed soil, cause disturbance of the soil structure close to the zone of failure, and the general arrangement makes it difficult to determine the effective diameter of the sample.

The actual influence of the above-

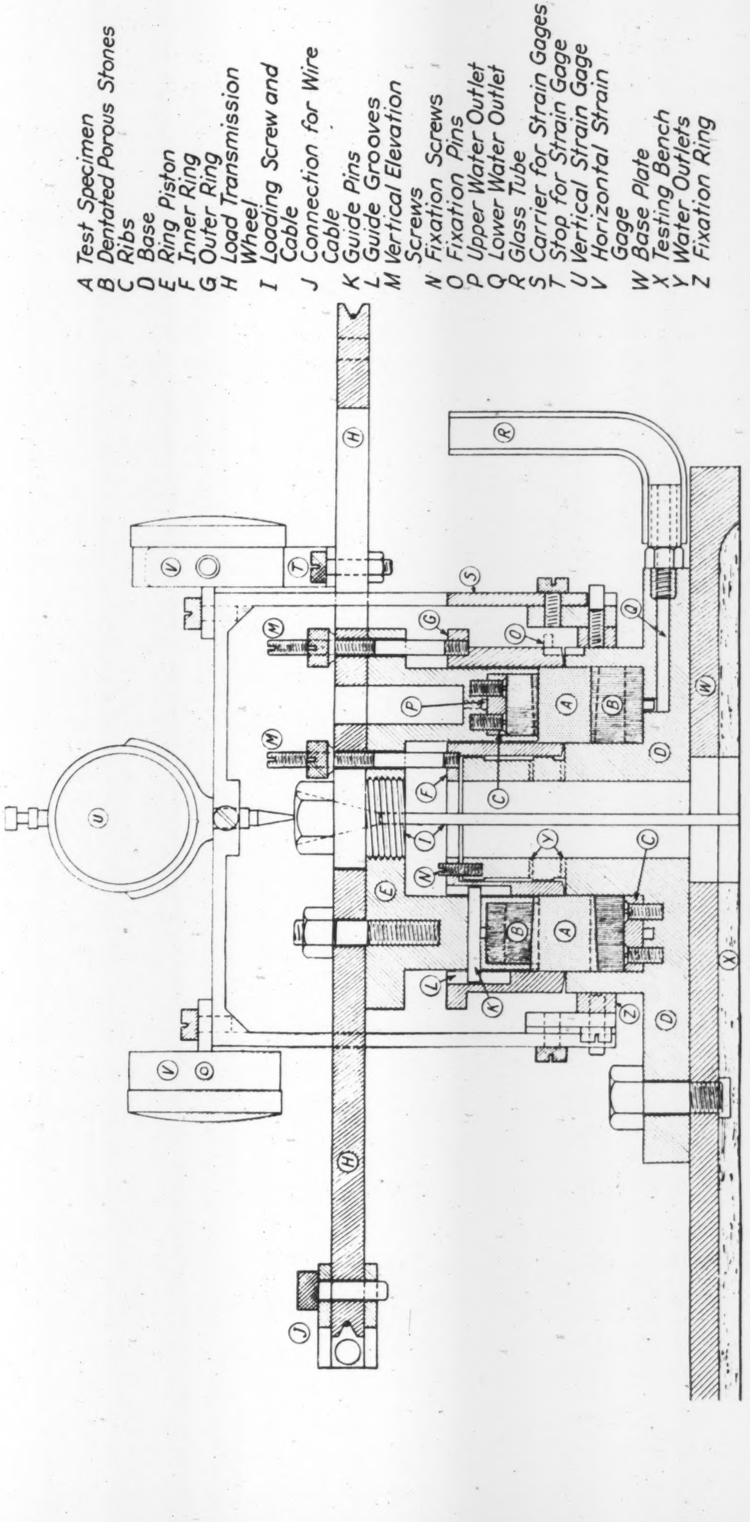

A Test Specimen
B Dentated Porous Stones
C Ribs
D Base
E Ring Piston
F Inner Ring
G Outer Ring
H Load Transmission Wheel
I Loading Screw and Cable
J Connection for Wire Cable
K Guide Pins
L Guide Grooves
M Vertical Elevation Screws
N Fixation Screws
O Fixation Pins
P Upper Water Outlet
Q Lower Water Outlet
R Glass Tube
S Carrier for Strain Gages
T Stop for Strain Gage
U Vertical Strain Gage
V Horizontal Strain Gage
W Base Plate
X Testing Bench
Y Water Outlets
Z Fixation Ring
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z

FIG. 6.—Ring Shearing Apparatus.

mentioned sources of error can only be determined by extensive experiments, and the author does not have sufficient data at hand to express an opinion on the reliability of the results of torsion shear tests on solid cylindrical samples. The author has been informed by Mr. Langer that, as a result of experiments with three apparatus of the type shown in Fig. 4, a new apparatus of the same type but embodying several improvements has been designed and will soon be built and tested.

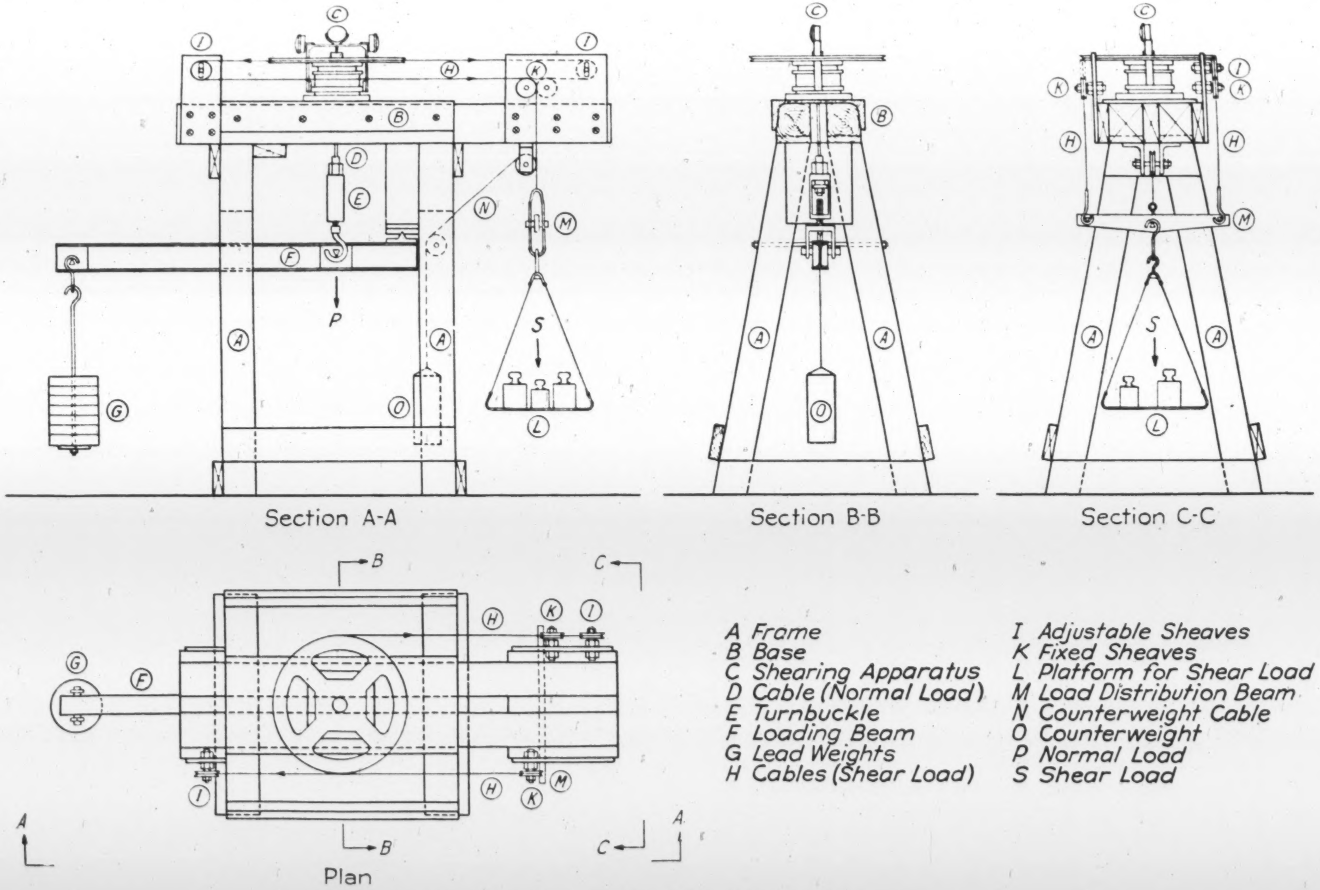
TORSION SHEAR TESTS ON RING-SHAPE SAMPLES

The most conspicuous disadvantage of torsion shear tests on solid cylindrical samples is that the shearing stresses and volume changes decrease to zero at the center of the sample. The first attempt to eliminate this disadvantage was made by Tiedemann (**15**) who in 1933 constructed the apparatus shown in Fig. 5. The cross-section of the sample and the piston through which the vertical normal force is exerted is still a solid circle, but the rotating part of the apparatus is a ring placed in the bottom of the cylinder containing the sample. Since the shearing stresses and volume changes are concentrated in a zone between a stationary core and an outer ring, there is danger that the soil will arch over the ring and it is even more difficult in this case to determine the distribution of normal stresses on the plane of failure and to correlate the vertical movements of the piston with the volume changes in the zone of failure than in the case of the apparatus shown in Fig. 4. To the author's knowledge, the apparatus shown in Fig. 5 has not been used to any great extent for practical tests, and Tiedemann replaced it in 1937 with the ring shearing apparatus shown in Fig. 9.

The above-mentioned principal objection to torsion shear tests on samples with solid circular cross-section can be lessened to a large extent but not entirely eliminated by using ring-shaped samples. Shearing apparatus of this type—the so-called ring shearing apparatus—were developed independently in 1934 by Gruner and Haefeli (**4**), Cooling and Smith (**2**), and by the author (**6**, **7**).

The ring shearing apparatus developed by the author is shown in Fig. 6. It was built in the Soil Mechanics Laboratory of the Vienna Institute of Technology with the aid of funds generously placed at the author's disposal by Terzaghi, under whose direction the research was carried out. The stationary part of the apparatus consists of a base plate with a ring-shaped groove for the sample, *A*, which has an internal diameter of 5.95 cm. and an external diameter of 11.95 cm. By means of inlays the height of the sample can be varied between 0.5 cm. and 3.0 cm.; a height of approximately 2.0 cm. was generally used. The rotating parts consist of the inner ring, *F*, the outer ring, *G*, the ring-shaped piston, *E*, and the wheel, *H*, through which the torsional moment is exerted. This moment is transmitted to the sample in part by the rings and the walls of the groove and in part by porous stones equipped with radial teeth, *B*. Four holes, *P*, in the piston and the glass standpipe, *R*, serve as water outlets and reservoirs. The vertical normal load is transmitted through the screw, *I*, and a very flexible steel cable.

The general arrangement for transmitting normal and shearing loads to the sample is shown in Fig. 7. This loading arrangement is of the stress-control type, which is preferable for investigation of the slow plastic flow before failure and for the determination of the maximum shearing resistance. For the purpose of investigation of the decrease in shearing resistance and the influence


C
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A
B
C
A
Plan
A Frame
B Base
C Shearing Apparatus
D Cable (Normal Load)
E Turnbuckle
F Loading Beam
G Lead Weights
H Cables (Shear Load)
I Adjustable Sheaves
K Fixed Sheaves
L Platform for Shear Load
M Load Distribution Beam
N Counterweight Cable
O Counterweight
P Normal Load
S Shear Load

FIG. 7.—General Assembly of Ring Shearing Apparatus.

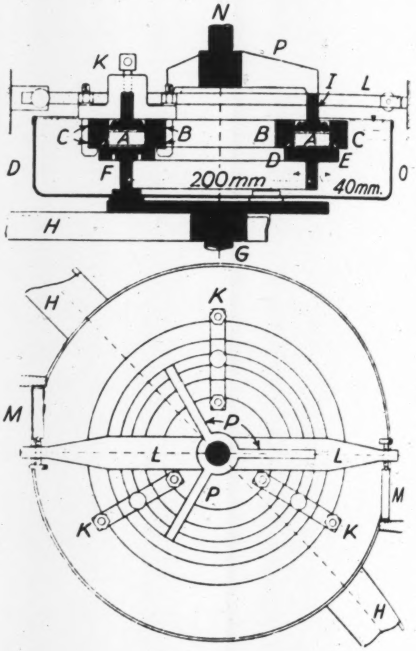
of the velocity of the rapid plastic flow after failure a loading arrangement of the strain-control type—as used in the Institute of Technology in Hanover, Germany, and developed independently in this country by Glennon Gilboy—is preferable. The shear tests can be performed in three different ways as follows:

1. By "restrained rings," whereby the pins, *K*, are inserted and force the rings to follow the rotary but not the vertical movements of the piston. The rings are raised from 1 to 2 mm. before the test by means of the screws, *M*. The narrow space under the raised rings is filled with heavy grease in order to prevent evaporation from the exposed surface of the sample.

2. By "free rings," whereby the pins, *K*, are left out so that the rotary movement of the rings is not governed directly by the movements of the piston. As in case No. 1, the rings are raised before the test by means of the screws, *M*.

3. By "fixed rings," whereby the rings are fastened to the base by means of the screws, *N*, and the pins, *O*. The pins, *K*, and the screws, *M*, are left out and the rings are not raised before the test. In this case failure of the soil takes place a short distance below the piston.

Comparative tests on remolded soils were performed with the three testing arrangements. Arrangements Nos. 1 and 2 gave nearly identical results; therefore the pins, *K*, are not necessary. On the other hand, these two testing arrangements gave from 2 to 10 per cent smaller values for the maximum shearing resistance, a smaller total twist, and larger vertical settlements of the piston than arrangement No. 3. The smaller values of the shearing resistance are undoubtedly caused by stress concentration at the edge of the rings and the larger settlements by soil being squeezed out in the narrow space under the rings. The ultimate minimum shearing resistance after failure was the same in all three cases. These results indicate that testing arrangement No. 3 is to be preferred for tests on remolded soils. No tests were made on samples of undisturbed soil. For such soils it would probably be best to use testing arrangement No. 2, since the soil structure in the immediate vicinity of the teeth of the porous stones may be partially disturbed and since the plane of failure, obtained with testing arrangement No. 3, is close to the underside of the piston. Furthermore, there is generally less danger of



A-Sample
B-Upper Inner Rings
C-Upper Outer Rings
D-Lower Inner Ring
E-Lower Outer Ring
F-Base Piston
G-Shaft
H-Lever
I-Upper Piston
K-Lifting Yoke and Bolts
L-Stationary Beam
M-Pendulum Supports
N-Shaft for Normal Force
O-Water Basin
P-Piston Yoke

FIG. 8.—Ring Shearing Apparatus by Haefeli. *Schweizer Bauzeitung*, Nos. 24 and 26 (1938).

soil being squeezed out under the raised rings when samples of undisturbed soils are used. Examples of the result of tests with this apparatus are given in Appendix I.

In their paper on "The Shearing Resistance of Soils," Cooling and Smith (2) give only a very brief description and furnish no drawings of the ring shearing apparatus which they have developed. The sample has an internal diameter of $3\frac{1}{4}$ in. and an external diameter of 4 in.; its height can be varied between 1 and $1\frac{1}{2}$ in. The tests were conducted without any external normal loads and the vertical sides of the sample were exposed to the atmosphere instead of being confined between metal rings. In view of the fact that the friction and stress concentrations caused by the metal rings are eliminated, the agreement between the actual and theoretical stress distribution is better in this apparatus than in the other types of ring shearing apparatus described in this paper. On the other hand, the sample is subjected to capillary forces which change during the test and cannot be determined with satisfactory accuracy. Therefore, the effective normal stress on the plane of failure, the coefficient of internal friction, and the true cohesion of the soil cannot be determined by means of this apparatus; only the total shearing resistance for a given void ratio is obtained. The results of the tests are directly comparable with the results obtained by unconfined compression tests and, according to the published results, the agreement is satisfactory.

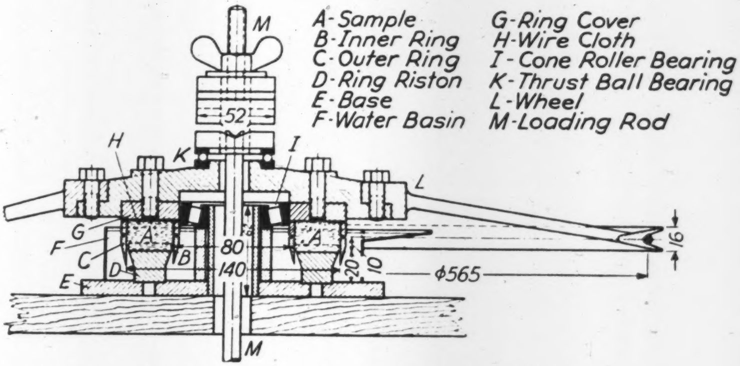


FIG. 9.—Ring Shearing Apparatus by Tiedemann.
Die Bautechnik, Nos. 30 and 33 (1937).

The ring shearing apparatus developed by Haefeli (5) and built in the Federal Institute of Technology in Zurich is shown in Fig. 8. The sample has an internal diameter of 16.0 cm. and an outside diameter of 24.0 cm. and is confined by inner and outer rings. The upper piston, *I*, and the upper rings (*B* and *G*) are held stationary by the beam, *I*, and the pendulum supports, *M*, while the base piston, *F*, is rotated by means of the lever arm, *H*. Both pistons are provided with radial ribs for transmission of the torsional moment to the sample. The vertical normal load is transmitted to the piston through the rod, *N*, while the thrust on the rotating base is taken up by the shaft, *G*, which rests on a steel ball; the friction due to rotation of the base is thereby reduced to a negligible amount. The upper rings are raised before the test by means of the yokes and bolts, *K*. A large basin, *O*, is attached to the base and filled with water, so that the rings and the sample are submerged during the test.

A similar ring shearing apparatus, designed by Tiedemann (**15**) and built in the Preussischen Versuchsanstalt für Wasser-, Erd-, und Schiffbau in Berlin, Germany, is shown in Fig. 9. The sample has an internal diameter of 8.0 cm., an external diameter of 14.0 cm., and a height of 2.0 cm. It is confined in part by the inner and outer rings *B* and *C* and in part by the ring-shaped cover, *G*, which is provided with radial ribs and fastened to the wheel, *L*. The cover and wheel are guided by the cone roller bearing, *I*. The piston, *D*, is also provided with radial ribs and is connected to the base, *E*, by means of taps and thereby held in stationary position during the test. The spaces between the ribs are covered with wire cloth in order to facilitate drainage. The rings and the sample are submerged in water, contained in a basin formed by the cylinder, *F*. The vertical normal load is transmitted through the thrust ball bearing *K* and the rod *M*.

The test specimens are prepared and placed in the apparatus in the following manner. The sample is roughly cut to the required dimensions; the rings *B* and *C*, which have a height of 2.0 cm., are held in a template and gently forced down into the sample. The template is then removed and the ends of the sample cut off flush by means of a wire saw. The ring-shaped cover *G* is placed on a table in an inverted position; the rings containing the sample are then placed on top of the cover and the sample forced into the cover by means of the piston *D*. The assembly is then turned over and placed on the base plate. This procedure is also used for tests on remolded soils, which are consolidated under the desired normal load in the boxes of a translatory shearing apparatus. The number of tests which can be made with the ring shearing apparatus in a given time is thereby increased. However, the transfer of the samples from the boxes of the translatory shearing apparatus to the ring shearing apparatus with consequent unloading and reloading and the possibility of disturbance of the soil during the preparation of the ring-shaped sample may in some cases be objectionable. When the shearing boxes or the sampling tubes, by means of which the undisturbed samples have been obtained, have a diameter less than 14.0 cm., the sample for the shearing test is composed of ring-shaped segments, cut by means of special templates. Examples of the results of tests made with this apparatus are given in Appendix I.

In comparison with apparatus for torsion tests on solid cylindrical samples, the ring shearing apparatus has the disadvantage that it is somewhat more difficult to prepare and place samples of undisturbed soil, but it has the advantage of a much more uniform distribution of angular displacements and corresponding shearing stresses and thereby also greater uniformity of volume changes and normal stresses on the plane of failure. This uniformity increases theoretically with decreasing thickness of the soil ring, but the influence of the friction between the sample and the rings and of the stress concentration at the edge of the raised rings will also increase and it is probable that the wall thickness or the ratio between the internal and external diameters of the ring should not be reduced beyond a definite value which must be determined by tests. In the various ring shearing apparatus constructed to date the ratio between the internal and external diameters of the soil ring varies between 0.5 and 0.8 but, to the author's knowledge, experiments to determine the best value have not yet been made.

According to Tiedemann (**15**), the ring shearing apparatus furnishes values of the maximum shearing resistance which are in close agreement with those obtained by means of the translatory shear test. In tests with remolded clays the author (6) found a similar agreement, although the ring shearing apparatus in some tests with overconsolidated soils gave from 10 to 13 per cent smaller values of the maximum shearing resistance than the translatory shear test. In case of shear tests on undisturbed soil and small vertical loads, the torsion shear tests will probably furnish more reliable values of the maximum shearing resistance than the translatory shear test, as there is less danger in the case of the torsion shear test that the piston will tip or "ride" over the sample.

The torsion shear test on ring-shaped samples is the best type of test, so far devised, for determination of the decrease of the shearing resistance and the influence of the velocity of the rapid plastic flow on the stress-strain curve after failure. This type of test is also suited for investigation of the slow plastic flow before failure. However, for determination of the maximum shearing resistance it is, in the author's opinion, in most cases inferior to the triaxial shear test.

APPENDIX I

EXAMPLES OF RESULTS OF TORSION SHEAR TESTS

The results of torsion shear tests on four different clays are shown in Figs. 10 to 13. The characteristics of the soils are given in the figures. The tests on Vienna clay and Little Belt clay were made by the author, those on London Clay by Langer (8), and those on the Weser-Elbe Clay by Tiedemann (15). The apparatus shown in Fig. 6 was used for the tests on the three first-mentioned soils and the apparatus shown in Fig. 9 for the tests on the Weser-Elbe clay.

The results of a preliminary test to determine the bond resistance and the velocity of the slow plastic flow of Little Belt clay are shown in Fig. 10. The soil was remolded and after consolidation under 5.0 kg. per sq. cm. allowed to swell under the reduced load of 1.0 kg. per sq. cm. In this state of strong over consolidation the change in void ratio during the test—here an increase—is very small. The twist θ of the apparatus is given in radians; since the external diameter of the sample is 12 cm., the maximum displacements are $60 \times \theta$ mm. The last parts of the time twist curves are plotted in the lower right corner of Fig. 10. These curves show that the velocity of the slow plastic flow has reached a fairly, although not completely, constant velocity 240 hr. after the load application. By plotting this velocity—indicated by the tangent lines in the upper left corner—against the average shearing stresses τ_a we obtain the stress-flow curve, which shows that the slow plastic flow starts at $\tau_a = 0.15$ kg. per sq. cm. = 30 per cent of the maximum shearing resistance and that the velocity of the flow increases more or less linearly with the increase in shearing stresses. The actual bond resistance is probably a little higher than 0.15 kg. per sq. cm. since the time interval of 240 hr. between load applications is not long enough to allow the ultimate constant velocity of the slow plastic flow to be reached.

The stress-strain curves of the four soils are shown in Figs. 11, 12 and 13. The stress-strain relationships of Vienna clay and Little Belt clay were determined by the method shown in Fig. 17, Appendix II, while it is possible that the average shearing stresses—Eq. 2 in Appendix II—were used in plotting the results of the tests on Weser-Elbe clay. The principal results of these tests are the following:

Vienna Clay.—The ultimate minimum value of the shearing resistance after failure is 83 and 72 per cent of the maximum shearing resistance, respectively, for natural and over consolidated clay. These minimum values are reached by twists of 0.38 and 0.057 radians, corresponding to displacements of 24 and 4 mm. along the outer surface of the sample. The curve in Fig. 11(*a*) shows a temporary minimum of 73 per cent, which undoubtedly is due to a temporary excess pressure in the pore water, caused by remolding during the rapid plastic flow after failure. Details of this test are shown in Fig. 18.

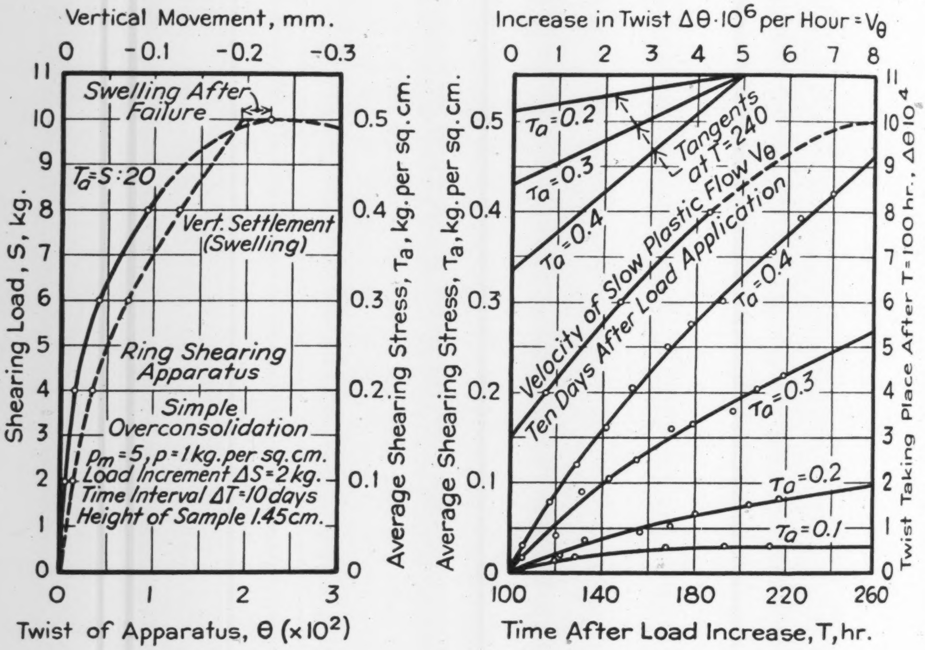
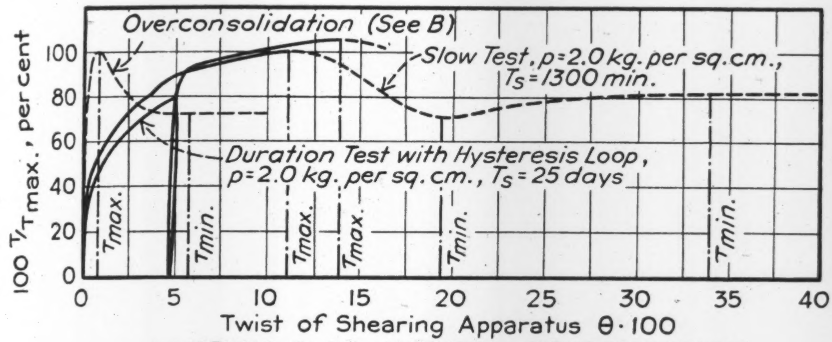


FIG. 10.—Little Belt Clay. Velocity of slow plastic flow before failure.

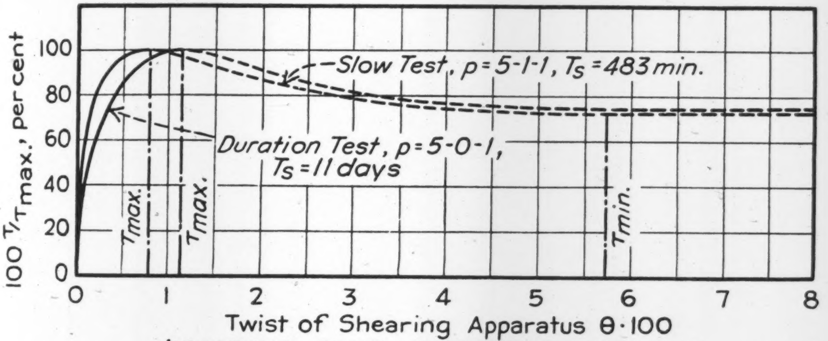
Little Belt Clay.—The minimum value of the shearing resistance after failure is 40 and 30 per cent of the maximum value, respectively, for natural and over consolidated clay. The corresponding twists are 0.5 and 1.3 radians or maximum displacements of 30 and 78 mm.

London Clay.—The minimum values of the shearing resistance vary from 55 to 62 per cent of the maximum values and are reached by twists of 20 to 35 deg. or maximum displacements of 21 to 37 mm.

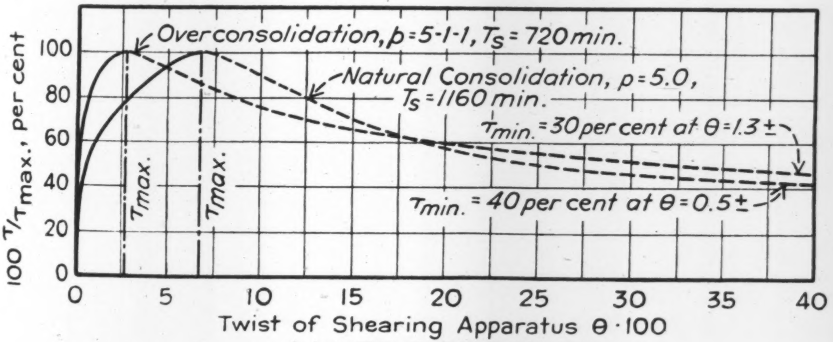
Weser-Elbe Clay.—In case of tests on undisturbed soil the minimum values of the shearing resistance vary from 30 to 44 per cent of the maximum values and are reached by displacements of about 10 cm. For the remolded soil the minimum values are 44 to 45 per cent of the maximum values and the corresponding displacements about 14 cm. These large displacements indicate that the shearing stresses represent the average shearing stresses. If this is the case and the stress-strain relationships were to be determined by the method shown in Fig. 17, the displacements corresponding to the minimum values of the shearing resistance would be reduced to about 60



(a) VIENNA CLAY – NATURAL CONSOLIDATION



(b) VIENNA CLAY – OVERCONSOLIDATION



(c) LITTLE BELT CLAY

FIG. 11.—Stress-Strain Curves for Shear Before and After Failure.

All tests performed on remolded soil with the ring shearing apparatus, Fig. 6.
Little Belt Clay.—Liquid limit 125.7 per cent, plastic limit 35.5 per cent, grain diameter 93 per cent < 0.005 mm.
Vienna Clay.—Liquid limit 45.6 per cent, plastic limit 21.1 per cent, grain diameter 38 per cent < 0.005 mm.

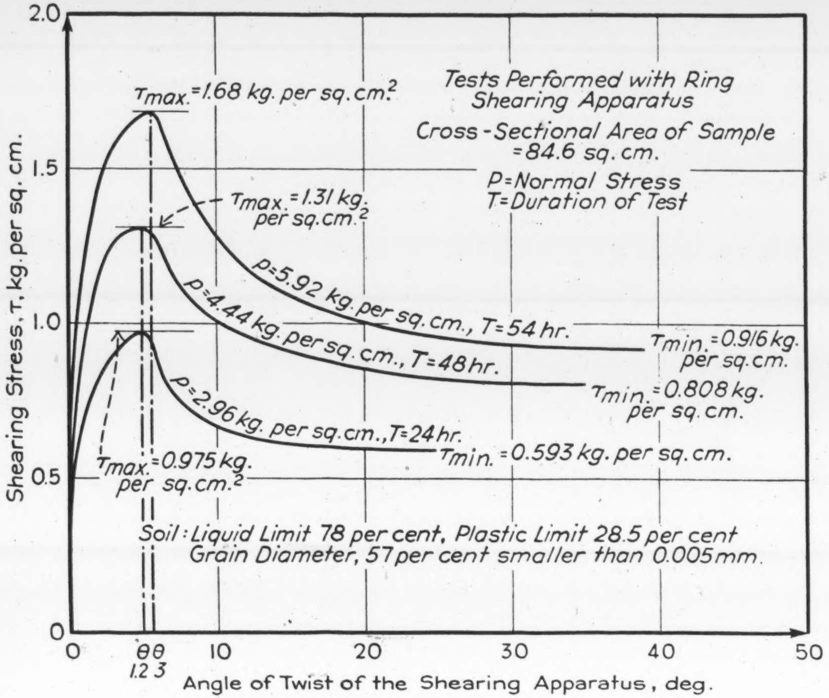


FIG. 12.—Torsion Shear Test on Remolded London Clay.

C. Langer, "Propriétés Mécaniques et Physiques des Terrains Cohérents," Laboratoire du Batiment et des Travaux Publics, *Compte Rendu* (1938).

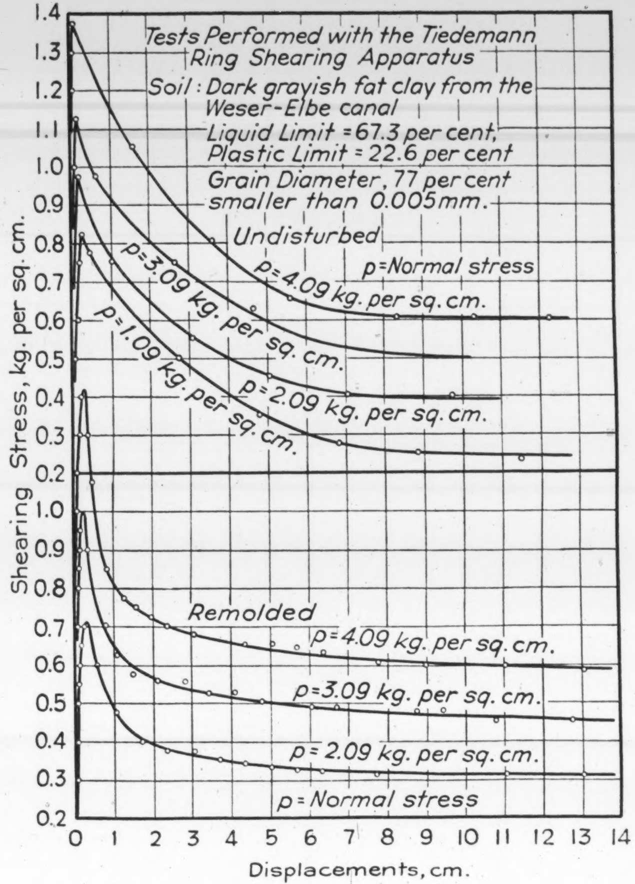


FIG. 13.—Torsion Shear Tests on a Dark Fat Clay from the Weser-Elbe Canal.

B. Tiedemann, "Über die Schubfestigkeit Bindiger Böden," *Die Bautechnik*, Nos. 30 and 34 (1937).

per cent of the displacements shown in Fig. 13. The curvature of the stress-strain curves at the point of failure appears very sharp in case of this clay, but this is primarily the result of the small scale used in plotting the displacements.

APPENDIX II

STRESS AND STRAIN THEORY OF TORSION SHEAR TESTS

The direct result of torsion shear tests is a series of corresponding values of the total torsional moment and the twist of the sample. From these results it is desired to determine the stress-strain relationship for shear and, particularly, the maximum and minimum values of the shearing resistance. In the following only the formulas for a ring-shaped sample, Fig. 14, will be given, since the formulas for the solid cylindrical sample can be obtained by setting the internal diameter $R_1 = 0$.

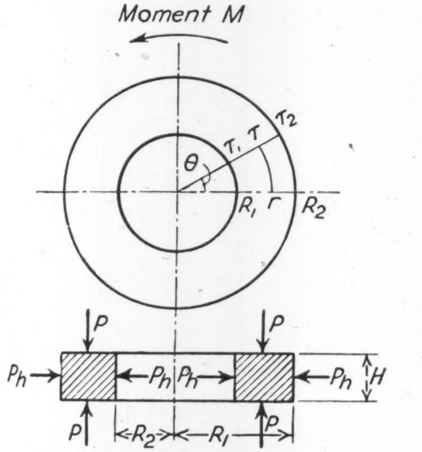


FIG. 14.—Soil Cylinder in Torsion.

In case of torsion tests on elastic, brittle materials it is often assumed that the shearing stresses vary directly with the distance from the axis of the sample. This assumption corresponds to the stress-strain curve O-A in Fig. 15 and leads to the well-known formula for the shearing stress τ_e at the outer cylindrical surface of the sample,

$$\tau_e = \frac{2MR_2}{\pi(R_2^4 - R_1^4)} \dots\dots\dots\dots (1)$$

where M = the torsional moment. The shearing resistance or maximum shearing stress at failure cannot be determined by means of this formula unless there is an instantaneous and very material drop of the stress-strain curve after failure. If the formula is applied to torsion shear tests on soils, it will furnish values for the maximum shearing resistance which are much higher that the actual values. The error increases with the ratio R_2/R_1 and may reach 30 per cent for a solid sample.

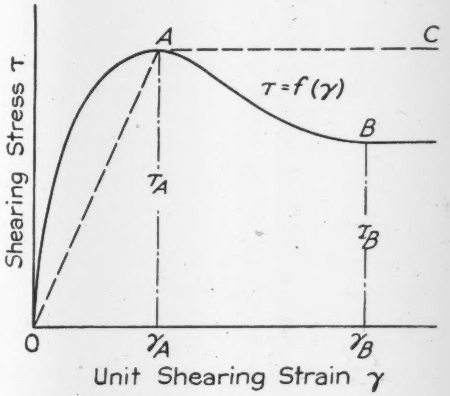


FIG. 15.—Soil Stress-Strain Curve for Shear.

In the case of torsion tests on plastic materials it is commonly assumed that the shearing stresses are uniform throughout the zone of failure. This assumption corresponds to the stress-strain curve O-A-C in Fig. 15 and leads to the formula:

$$\tau_a = \frac{3M}{2\pi(R_2^3 - R_1^3)} \dots\dots\dots\dots (2)$$

If this formula is applied before failure, it will give the average shearing stress; hence the designation τ_a. As will be shown later, the formula gives reasonably correct values for the maximum and minimum shearing resistance of soils, but it should not be used for determination of the stress-strain curve.

At this point it should be mentioned that the planes of failure in a cylinder of a material with considerable internal friction and subjected to pure torsion will not be perpendicular and parallel to the axis of the cylinder. This fact has been proved experimentally by Cooling and Smith (2). The inclination of the planes of failure in a material to which Mohr's condition of failure applies is shown in Fig. 16. Therefore, if the torsion shearing apparatus produces a plane of failure which is perpendicular to the axis of the sample, we know that we are no longer dealing with pure torsion and pure shear but have introduced extraneous forces and complicated stress conditions.

Duguet-Ludwig-Prandtl have shown that, by making certain less radical assumptions, the stress-strain curve for shear can be determined by graphical differentiation of the moment-twist curve (see Nadai (**10**)). The method was developed for a solid cylinder but is easily expanded for use on a ring-shaped soil sample.

The sample and the forces are shown in Fig. 14. It is now assumed that in the zone of failure all planes perpendicular to the axis remain plane, that the unit shearing strain varies directly with the distance r from the axis, that the vertical loads p and the horizontal pressures p_s are uniformly distributed and remain constant during the test, and, finally, that the friction between the sample and the rings of the shearing apparatus only causes a uniform concentration of the shearing strains, so that the shearing strain γ for the twist θ can be expressed by

$$\gamma = \frac{1}{c}\frac{\theta}{H}r \ldots\ldots\ldots\ldots (3)$$

or, by introducing the reduced height $h = cH$,

$$\gamma = \frac{\theta}{h}r \ldots\ldots\ldots\ldots (4)$$

The unknown stress-strain function, Fig. 15, may be written as

$$\tau = f(\gamma) \ldots\ldots\ldots\ldots (5)$$

By means of Eqs. 4 and 5 and assuming that the function $f(\gamma)$ is continuous throughout the interval under consideration, we obtain for the moment M,

$$M = 2\pi \int_{R_1}^{R_2} \tau r^2 \, dr = \frac{2\pi h^3}{\theta^3} \int_{\gamma_1}^{\gamma_2} f(\gamma)\gamma^2 \, d\gamma \ldots (6)$$

Since $\gamma_2 = \frac{\theta}{h} R_2$ and $\gamma_1 = \frac{\theta}{h} R_1$, the above integral is also a function of θ or

$$M = F(\theta) \ldots\ldots\ldots\ldots (7)$$

Assuming that this function and its first derivative are continuous, and since $f(\gamma)$ is independent of θ, differentiation with respect to θ gives

$$\frac{dM}{d\theta} = -\frac{3}{\theta}\frac{2\pi h^3}{\theta^3}\int_{\gamma_1}^{\gamma_2} f(\gamma)\gamma^2 \, d\gamma + \frac{2\pi h^3}{\theta^3}\left(\frac{\theta}{h}R_2\right)^2 \frac{R_2}{h} f\left(\frac{\theta}{h}R_2\right) - \frac{2\pi h^3}{\theta^3}\left(\frac{\theta}{h}R_1\right)^2 f\left(\frac{\theta}{h}R_1\right).$$

Since $\tau_1 = f\left(\frac{\theta}{h}R_1\right)$ and $\tau_2 = f\left(\frac{\theta}{h}R_2\right)$, the above equation can by means of Eq. 6 be reduced to

$$\tau_2 - \tau_1\left(\frac{R_1}{R_2}\right)^3 = \frac{3}{2\pi R_2^3}\left(M + \frac{\theta}{3}\frac{dM}{d\theta}\right) \ldots (8)$$

The left side of this equation has the same form as the Duguet-Ludwig-Prandtl equation but there are two unknowns on the right side. In order to solve Eq. 8 we construct, as shown in Fig. 17, the curve

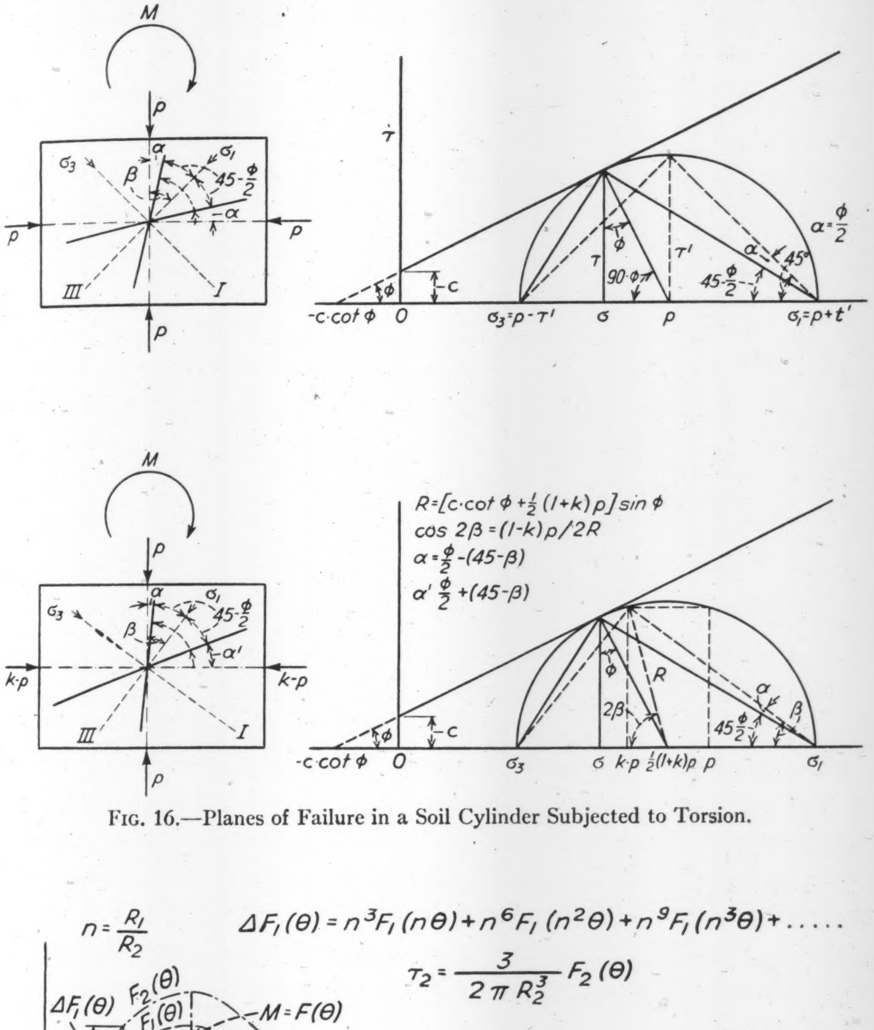
$$F_1(\theta) = M + \frac{\theta}{3}\frac{dM}{d\theta} \ldots\ldots\ldots (9)$$

and with

$$\frac{R_1}{R_2} = n \ldots\ldots\ldots\ldots (10)$$

Eq. 8 can be written as

$$\tau_2 = \frac{3}{2\pi R_2^3} F_1(\theta) + n^3\tau_1 \ldots\ldots (11)$$


M
p
σ3
α
σ1
β
45-φ/2
-α
p
p
III
I
p
τ
α=φ/2
φ
τ'
α
45°
τ
90-φ
45-φ/2
φ
c
-c·cot φ
O
σ3=p-τ'
σ
p
σ1=p+t'
M
p
R=[c·cot φ + ½ (1+k) p] sin φ
cos 2β = (1-k) p/2R
α = φ/2 -(45-β)
α' φ/2 +(45-β)
σ3
α
σ1
β
45-φ/2
-α'
k·p
k·p
III
I
p
φ
R
α
β
2β
45 φ/2
c
φ
-c·cot φ
O
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σ
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½(1+k)p
p
σ1

FIG. 16.—Planes of Failure in a Soil Cylinder Subjected to Torsion.

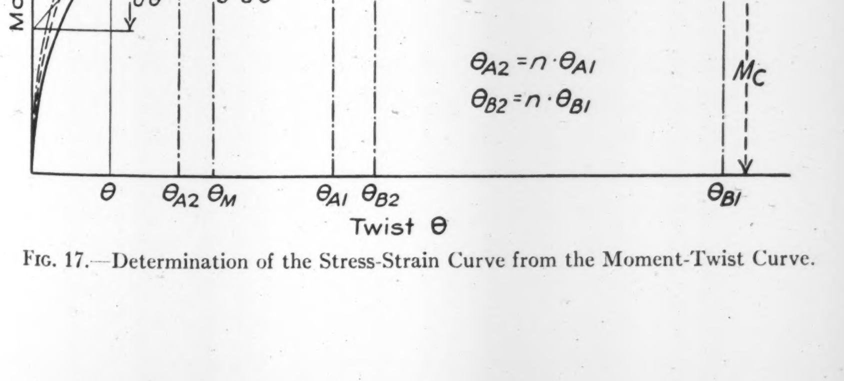

FIG. 17.—Determination of the Stress-Strain Curve from the Moment-Twist Curve.

By reason of Eqs. 4 and 5 we also have

$$\tau_1 = \frac{3}{2\pi R_2^3} F_1(n\theta) + n^3\tau_{(n\theta)} \quad \ldots\ldots (12)$$

and

$$\tau_{1(n\theta)} = \frac{3}{2\pi R_2^3} F_1(n^2\theta) + n^3\tau_{1(n^2\theta)}$$

etc.

The following equation is then obtained by summation:

$$\tau_2 = \frac{3}{2\pi R_2^3}\left(F_1(\theta) + n^3 F_1(n\theta) + n^6 F_1(n^2\theta) + n^9 F_1(n^3\theta) + \cdots\right) \quad \ldots (13)$$

and with

$$F_2(\theta) = F_1(\theta) + n^3 F_1(n\theta) + n^6 F_1(n^2\theta) + n^9 F_1(n^3\theta) + \cdots \quad \ldots (14)$$

$$\tau_2 = \frac{3}{2\pi R_2^3} F_2(\theta) \quad \ldots\ldots\ldots (15)$$

and

$$\tau_1 = \frac{3}{2\pi R_2^3} F_2(n\theta) \quad \ldots\ldots\ldots (16)$$

To the ordinates of the $F_1(\theta)$ curve in Fig. 17 we add

$$\Delta F_1(\theta) = n^3 F_1(n\theta) + n^6 F_1(n^2\theta) + n^9 F_1(n^3\theta) + \cdots \quad \ldots (17)$$

and obtain thereby the $F_2(\theta)$ curve, from which the shearing stresses τ_1 and τ_2 are computed by means of Eqs. 15 and 16. The series in Eq. 17 converges rapidly and it is generally sufficient to include the first two or three members. Furthermore, it is only necessary to compute the series in Eq. 17 for two or three small values of θ; when the first part of the $F_2(\theta)$ curve has been plotted, the remaining part can be obtained by means of the simpler equation

$$\Delta F_1(\theta) = n^3 F_2(n\theta) \quad \ldots\ldots\ldots (18)$$

The ordinates to the curves $F(\theta)$ and $F_2(\theta)$ in Fig. 17 represent the shearing stresses τ_a and τ_2, respectively. The moment $M = F(\theta)$ reaches its ultimate minimum value M_c for the twist θ_{B1} and remains constant from then on. At this point we have $\tau_a = \tau_1 = \tau_2$. The stresses τ_a and τ_1 also reach their ultimate minimum values for the twist θ_{B1}, while $F_2(\theta)$ and τ_2 attain their ultimate minimum values for the much smaller twist $\theta_{B2} = n \times \theta_{B1}$. This relation does not apply to a temporary minimum. The moment and τ_a reach their maximum values for the twist θ_M, while $F_2(\theta)$ and τ_2 attain their maximum values for the somewhat smaller twist τ_{A2}, but the ratio between the two twists depends in this case on the shape of the moment curve.

For the apparatus shown in Fig. 6 we have $R_1 = 2.975$ cm., $R_2 = 5.975$ cm., $n = \frac{1}{2}$, and $M = 19.64 \times S$ kg-cm., where S is the shear load (see Fig. 7). By introducing these values in Eqs. 2, 15, 16, and 17 and by using the load curve $S = F(\theta)$ instead of the moment curve $M = F(\theta)$, the following equations are obtained:

$$\tau_a = \frac{S}{20} \text{ kg. per sq. cm.} \quad \ldots\ldots\ldots (19)$$

$$F_1(\theta) = S + \frac{\theta}{3}\frac{dS}{d\theta} \quad \ldots\ldots\ldots (20)$$

$$\Delta F_1(\theta) = \frac{1}{8}F_1\left(\frac{\theta}{2}\right) + \frac{1}{64}F_1\left(\frac{\theta}{4}\right) + \frac{1}{512}F_1\left(\frac{\theta}{8}\right) + \cdots \quad \ldots (21)$$

$$\tau_2 = \frac{1}{22.8} F_2(\theta) \text{ kg. per sq. cm.} \quad \ldots\ldots (22)$$

$$\tau_1 = \frac{1}{22.8} F_2\left(\frac{\theta}{2}\right) \text{ kg. per sq. cm.} \quad \ldots (23)$$

An example of the determination of the various curves is shown in Fig. 18. The maximum values of τ_2 and τ_a are approximately equal. In other tests made by the author the value of τ_2 was only from 0 to 3 percent larger than the value of τ_a. The ultimate minimum values of these stresses are, of course, equal, but there may be considerable difference in temporary minimum values, and there is a very large difference in the twist at which either the temporary or ultimate minimum values of τ_2 and τ_a occur. Therefore, Eq. 2 may be used for the determination of the maximum and the ultimate minimum values of the shearing resistance, but this equation should not be used for determination of temporary minimum values of the shearing resistance nor for the determination of the stress-strain curves.

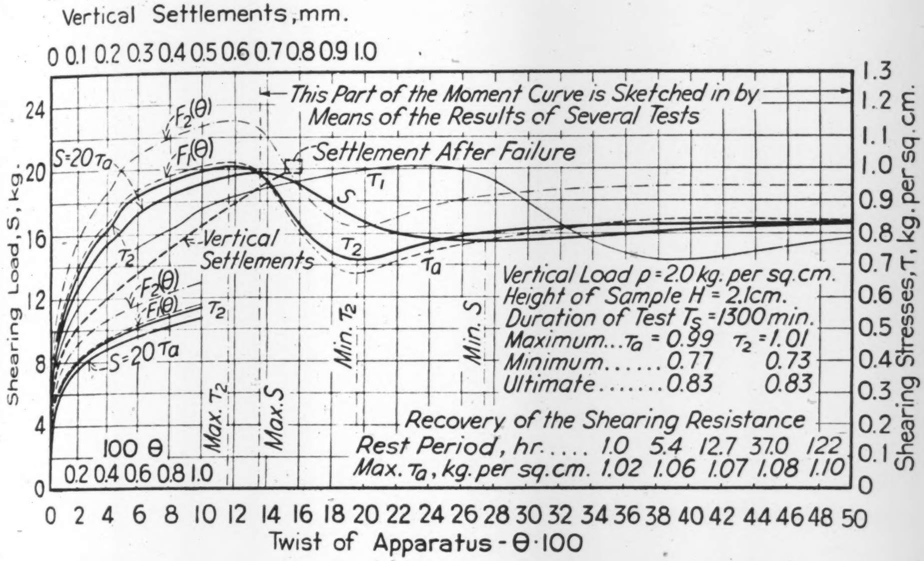

FIG. 18.—Vienna Clay, Test with the Ring Shearing Apparatus, Fixed Rings.

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SOME PRACTICAL ASPECTS OF SOIL SHEAR TESTING

By Gregory P. Tschebotareff[1]

As a result of the research work of numerous investigators it is generally recognized at present that the shearing resistance of a soil, especially that of a clay soil, can vary greatly with variations in the testing procedure and in the conditions under which the same basic soil material is tested.

At the same time we continue to find in technical publications data concerning the angle of internal friction or the total shearing resistance of a soil, with no indications being given concerning the method of testing or the state of the soil material to which the data refer. In the few cases where such limiting indications are given, it is still difficult or almost impossible to compare the results with others, since very few parallel tests on different types of soil shear testing machines have been performed or if they have been made hardly any such comparisons have been made available through publication.

The natural result of such conditions is a certain hesitancy among practising engineers to use data supplied by laboratory shear tests. Some engineers call for a standardization of the testing procedure in order to remedy this situation. Others are strongly opposed to any standardization on the grounds that it would hamper the much needed further research on the subject.

Both these two opposed views are justified to a certain extent and do not appear irreconcilable to the author. The main purpose of this paper is to outline possible ways for partial improvement of the present situation concerning correlation of shear test data and to promote discussion of this aspect of shear testing with which the American Society for Testing Materials is mainly concerned.

In the author's opinion one should strictly discriminate between:

1. Shear tests performed for the purpose of numerically estimating the actual shearing resistance of different types of undisturbed soils under varying field conditions, and

2. Shear tests performed for the purpose of selection of the most suitable soil by means of comparison of the shearing properties of different disturbed soils to be used as an engineering material in the field under identical conditions of recompaction.

Shear Tests for the Purpose of Numerical Estimation:

For the first of the above two types of shear tests a standardization of the testing procedure would appear to be not only harmful, but to be entirely impossible, at least for the present. The great variety of possible field conditions under which an undisturbed soil may be subjected to shearing stresses and deformations, combined with the variety of factors affecting the shearing resistance of a soil, renders it most inadvisable to impose for such cases any definite manner of soil shear testing. The decision as to what testing procedure would most closely approximate the field conditions should be left to the individual specialist performing the test, especially since his test results would in any case require interpretation prior to being applied to field design.

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[1] Assistant Professor of Civil Engineering, Princeton University, Princeton, N. J.

All that might reasonably be done in respect to this type of soil shear test so far as standardization is concerned should be limited to the preparation of instructions concerning the form for reporting shear test data in order to facilitate the correlation of test results performed by different investigators. In this connection it might be useful to enumerate some of the main factors which affect the shearing resistance of cohesive soils, that is of the soils which are most sensitive to variation in the shear testing procedure and which are further most apt to cause trouble in the field through shear failures.

For the same basic clay material, the following seven factors would mainly affect its shearing strength:

1. The "preconsolidation load," that is, the greatest previous pressure, due to overburden, to drying, or to other causes during the previous geological history of the soil deposit. The density and the cohesion of a clay soil would largely depend on the magnitude of this previous load. However, there does not appear to be any particular necessity to determine this load numerically, since it is the value of the cohesive forces that is of most practical interest and since this value, as well as the density of the clay, can be determined directly.

2. The percentage of consolidation under the normal load applied. It is well established at present that the shearing resistance increases with the density of a clay as its consolidation progresses. The effect of incomplete consolidation is relatively negligible where originally compact soils are concerned; that is, soils which had been already consolidated in the past under large "pre-consolidation" loads. But this same effect may be considerable and therefore may have a great practical importance where originally weak and unconsolidated clays and muds of a high water content have to be dealt with in the field.

3. The rate of application of the shearing force also affects the shearing resistance of a clay soil, which resistance decreases with a decrease in the total time of the shear test.

Results of shear tests made at Princeton University on Detroit clay given in Fig. 1 illustrate this relationship. The tests were performed in a fully submerged condition on a controlled shearing stress machine of simple design,[2] under normal loads of 0.1; 0.5; 1.0 and 3.0 tons per sq. ft. The basic material of this Detroit clay had the following properties:

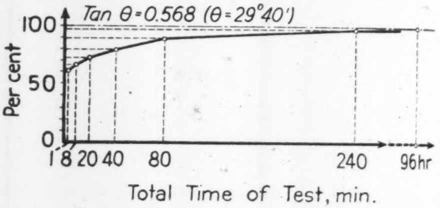

FIG. 1.—Results of Tests on Detroit Clay Show Dependence of the Shearing Resistance on the Rate of Application of the Shearing Force.

Mechanical Analysis, per cent:	
Coarse sand (2.0 to 0.25 mm.)	3
Fine sand (0.25 to 0.05 mm.)	12
Silt (0.05 to 0.005 mm.)	28
Clay smaller than 0.005 mm.	57
	100
Colloids, smaller than 0.001 mm.	32
Liquid limit, per cent	36
Plastic limit, per cent	18
Shrinkage limit, per cent	16

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[2] G. P. Tschebotareff, "Simple Soil-Test Machine," *Engineering News-Record*, Vol. 121, November 10, 1938, p. 581.

Prior to the tests, the clay was fully remolded and its water content was brought up to the liquid limit. After the test, the water content was again determined for a check. An unsuccessful attempt was then made to correlate the ultimate shearing resistance to the water content at the end of the test; whereas for the same normal loads the shearing resistance consistently increased with the increase in the duration of the test, the corresponding water contents, which ranged from 34 per cent to 20 per cent according to the normal load applied, did not exhibit any definite relationship with the shearing resistance and were rather erratic in this respect.

Another fine-grained soil tested recently by the author (the basic soil material consisted of decomposed leached granite) did not exhibit any increase of its shearing resistance with a longer duration of the test.

It seems to be still an open question whether the soils exhibiting such an increase do that because of additional consolidation during the tests of longer duration, or because of changing stresses in the water filling the voids or because of thixotropic phenomena or of other causes. It is still a subject for further research.

4. Some clays lose part of their shearing strength when remolded and may or may not regain it with time. With certain types of clays the thixotropic regain of strength appears to be very rapid and therefore may affect the results of shear tests of long duration. The ring shearing apparatus appears to be particularly well suited for research studies of such thixotropic phenomena.

5. The variation of the shearing resistance with the total deformation sustained is another factor of considerable practical importance. Tests made at Massachusetts Institute of Technology[3] with a controlled strain machine of novel design have disclosed interesting facts concerning this relationship which varied with the type of soil tested.

6. The shearing resistance of a soil mass as depending on the principal stresses acting within that mass is being investigated by tests made with the so-called triaxial compression devices. Research with these devices promises to increase our insight into the phenomena of shearing resistance.

7. Last, but not least, comes the effect of the size of the shear sample itself which effect appears to have been only partially investigated to date.

The preceding brief discussion should serve to show that we are yet far from having reached the stage where one could recommend any definite and uniform procedure of soil shear testing for the purpose of numerically determining the actual shearing resistance of a soil mass in the field. Numerous factors affect this resistance and their relative importance is likely to remain a subject for further research for some time to come. Different types of apparatus are best suited for the study of each of these factors and the existence of these different types is therefore fully justified at present.

Shear Tests for the Purpose of Selection of Soils:

However, for cases where arises the practical question of selection of a most suitable soil to be used as an engineering material (for dams, embankments, etc.), a definite testing procedure could and should be worked out to provide a uniform basis of comparison.

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[3] H. A. Fidler, "A Machine for Determining the Shearing Strength of Soils," published by Massachusetts Institute of Technology, June, 1938.

D. W. Taylor, "Shearing Properties of Ottawa Standard Sand as Determined by the M.I.T. Strain-Control Direct Shearing Machine," published by the Massachusetts Institute of Technology, June, 1938.

Sometimes on the same building site one meets possible borrow pits with soil material the engineering properties of which cannot be differentiated by mere visual inspection but which may be found to differ considerably if tested in a laboratory. For instance, the author made soil investigations for the rolled fill of the Inland Dam in Alabama where two types of clay from different borrow pits were being considered for the upstream face clay blanket. One was red and the other was yellow. They were tested on the same machine, by the same testing procedure and both were prepared for testing by two different methods each. Method A involved the complete remolding of the clay under addition of water over the liquid limit, then reconsolidation in the shear boxes under the normal loads of the shear test. Method B involved the crushing and the tamping into the shear boxes of the fairly compact clays (app. voids ratio $e = 0.55$) in a manner imitating the conditions of field compaction of the fill, then submersion for 24 hr. in the shear boxes.

	Method A		Method B	
	Angle of Internal Friction, θ, deg.	Cohesion, c, psi.	Angle of Internal Friction, θ, deg.	Cohesion, c, psi.
Red clay	26	0	22	2.6
Yellow clay	11	0	17	2.7

The above table gives the test results. It may be seen that this particular type of red clay definitely is a material with more advantageous shearing properties than yellow clay. This was not at all apparent at first from visual inspection alone; neither did a granular analysis, performed in the standard A.S.T.M. manner, give any indications as to this fact. A contrary conclusion might have even been reached on this basis since the red clay had more fine particles than the yellow clay (the red clay had 60 per cent particles smaller than 5 μ and 30 per cent smaller than 1 μ; the yellow clay had 50 per cent and 15 per cent, respectively).

This case may serve as an example of the practical utility of shear tests when a selection of suitable soils for fills, etc., is required. It may also illustrate the necessity to have a definite testing procedure in order to provide a common basis of comparison. Thus the above conclusions concerning the two types of clay discussed would have been much less or even not at all apparent had the tests been performed in one laboratory by method A on the red clay with, say, 15 min. for the total time of test, and by method B on the yellow clay in another laboratory with, say, 24 hr. for the total time of the test.

In closing, it should be mentioned that the manner of preparation for testing of a soil sample may strongly affect the test results even in the case of noncohesive soils. Further, the procedure used for the compaction of a sand will not be the only factor affecting the shearing resistance, since other factors too may affect the density of a sand; in making this statement the author assumes that it is generally known at present that a compact sand will have a higher value of shearing resistance than will a loose sand.

A sand slightly moistened *before* being placed in a shear box will have a lesser shearing resistance than the same sand placed in the same manner in the shear box, but either fully dry or fully submerged. This phenomenon is presumably due to the decrease in the density of a moist and reshovelled sand, due to bulking phenomena. For instance, tests made at Princeton University showed that an addition of 6 per cent moisture to the sand prior to it being placed in the shear box decreased the shearing resistance by about 12 per cent for Ottawa standard sand (passing No. 14 sieve and retained on No. 28 sieve). For a finer sand (passing No. 50 sieve and retained on No. 200 sieve) this decrease of the shearing resistance reached 23 per cent since the bulking here was more considerable. Naturally, no such decrease in the shearing resistance would occur if the sand was moistened *after* it was placed in the shear boxes. In this case a slight increase might have even become possible for very fine sands as a result of capillary forces. It therefore appears logical to recommend testing sands either in a fully dry or in a fully submerged condition.

ESSENTIAL FEATURES OF TRIAXIAL SHEAR TESTS

By C. A. Hogentogler[1] and E. S. Barber[1]

Tests to determine relations of the lateral to applied vertical pressures on soil and their use to furnish design data have become accepted practice.

In 1900 J. A. Jamieson (**1**),[2] a Canadian engineer, utilized manometers as shown in Fig. 1 to measure both the lateral and vertical pressures of grain in model bins. About the same time, E. P. Goodrich, investigating pressures against retaining walls utilized the apparatus shown in Fig. 2, and his findings published in 1904 (**2**) are substantiated by later work in this country (**3**, **4**) and quite recently by extensive investigations in Germany (**5**).

On January 18, 1933, Francis N. Hveem filed an application for letters patent on a stabilometer, Fig. 3, to test various sorts of reasonably stiff plastic materials, such as clay, soil (to determine bearing values), etc. (**6**). The apparatus had essential features as follows:

1. Flexible cylinder arranged concentrically within a cylindrical shell forming a pressure chamber between the two.
2. Specimens in a flexible cylinder loaded axially and means to measure accompanying changes in the chamber pressures.
3. Means to measure deformations of the specimens in the direction of load and perpendicular to it. The patent was granted April 23, 1935.[3]

Since 1933 reports on triaxial shear or stabilometer tests have been made by a number of others. Among contributors to the subject referred to in this report may be listed: Leo Jürgenson, 1934 (**7**); Keverling Buisman, 1934 (**8**); Delft Laboratories, 1936 (**9**); W. S. Housel, 1936 (**10**); Seibert and Palmer, 1938 (**11**); John D. Watson, 1938 (**12**); Corps of Engineers U. S. Army, 1939 (**13**); and the Bureau of Public Roads, Levi Muir, the Shell Oil Co. and the Bureau of Reclamation in 1939 (**14**).

The varied purposes of the tests, types of soil investigated, and laboratory facilities available necessitated procedures and equipment which varied widely in some respects and yet had enough in common to suggest the use of simplified apparatus with interchangeable parts to satisfy all the requirements. The methods employed include a "closed" system which prevents volume change of samples and an "open" system which permits their swell or consolidation during test. An impervious encasement which prevents entrance or escape of air and water encloses samples in the closed system, and placing them between porous stones provides for the entrance or egress of air and water in the open system.

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[1] Senior Highway Engineer, and Junior Highway Engineer, respectively, Division of Tests, U. S. Public Roads Administration, Washington, D. C.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 1044.

[3] U. S. Patent No. 1,998,722.

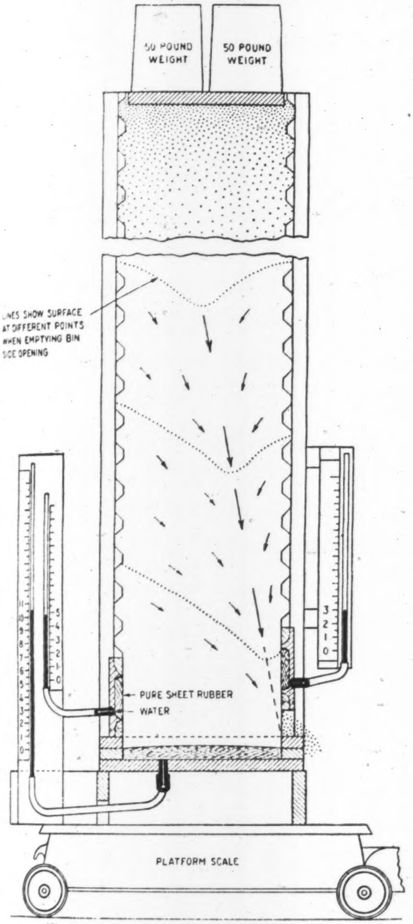

50 POUND WEIGHT
50 POUND WEIGHT
LINES SHOW SURFACE AT DIFFERENT POINTS WHEN EMPTYING BIN SIDE OPENING
PURE SHEET RUBBER
WATER
PLATFORM SCALE

FIG. 1.—Manometer Used by Jamieson.

THREE KINDS OF EARTH PRESSURE CONSIDERED IN DESIGN

Without movement of the earth, pressures against the walls, Fig. 4 (*a*) and (*b*), become the "earth pressures at rest" which depend upon the coefficient K, expressed by the relation:

$$K = \frac{l}{v}$$

where

l = lateral pressure, and
v = vertical pressure.

However, soil must deform to fail. The pressures it produces at maximum deformation without failure are termed "active" or "passive," depending on

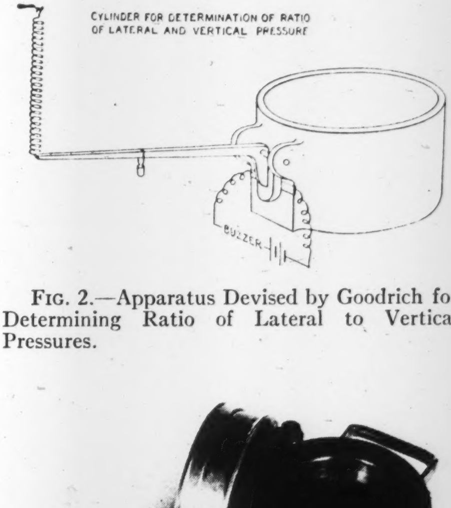

CYLINDER FOR DETERMINATION OF RATIO OF LATERAL AND VERTICAL PRESSURE
BUZZER

FIG. 2.—Apparatus Devised by Goodrich for Determining Ratio of Lateral to Vertical Pressures.

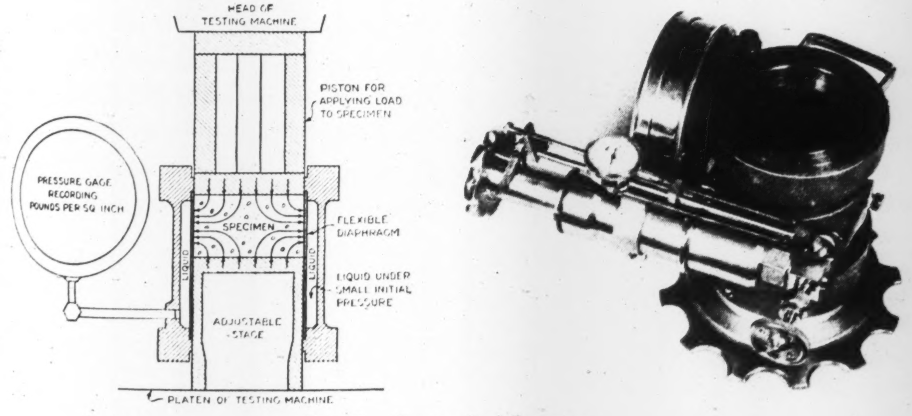

HEAD OF TESTING MACHINE
PISTON FOR APPLYING LOAD TO SPECIMEN
PRESSURE GAGE RECORDING POUNDS PER SQ. INCH
SPECIMEN
FLEXIBLE DIAPHRAGM
LIQUID
LIQUID
LIQUID UNDER SMALL INITIAL PRESSURE
ADJUSTABLE STAGE
PLATEN OF TESTING MACHINE

FIG. 3.—Hveem Stabilometer.

the directions of the applied forces responsible.

Wedges (**15, 16**) assumed in the design of retaining walls, Fig. 4, have lower boundaries, *D-D*, on which soil slips when it shears. Weight of the earth in Fig. 4 (*a*) produces the active earth pressure which forces walls outward and causes *D-D* to incline at an angle *a* with the horizontal and *b* with the vertical. Forcing walls backward as in Fig. 4 (*b*), produces the passive earth pressure.

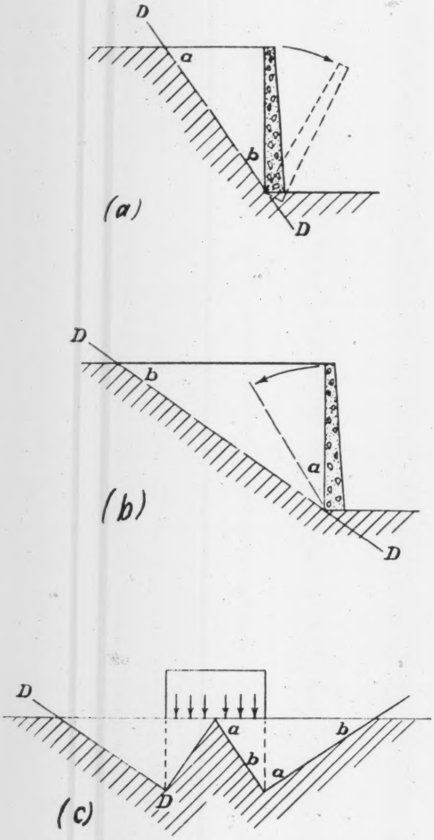


FIG. 4.—Surfaces of Slip Illustrated.

The diagram of supporting value of soil under a strip load, considered in a formula published in *Public Roads* (**17**), is shown in Fig. 4 (*c*).

Beneath each half of the load which acts like an embankment breaking in the middle is a triangular diagram of active earth pressure similar to the one in Fig. 4 (*a*). It is assumed that wedges of earth beneath the surface adjacent in to the loaded area and subjected to passive earth pressure function like

FIG. 5.—Rubber Sleeve and Clamps Used to Encase Samples for Stabilometer Tests.

retaining walls to prevent failure of the wedges subjected to the active earth pressure. Therefore, diagrams of passive earth pressure similar to the one in Fig. 4 (*b*) are used to complete the diagram of the supporting value of the soil (Fig. 4 (*c*)). The angle *a* and its complement *b* are utilized also in the theories suggested for the determination of stresses in embankments (**18**), soil foundations for rigid loads (**19**), and flexible type pavements (**20, 21**).

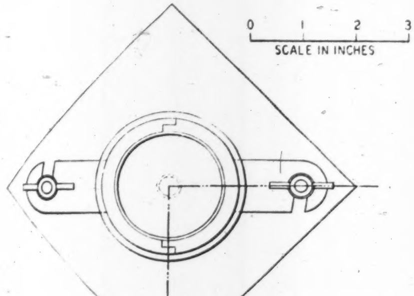


FIG. 6.—Mold Used for Compacting Samples for Stabilometer Tests.

The coefficient of earth pressure at rest, *K*, as stated elsewhere (**22**) depends upon the soil's elasticity rather than its resistance to shear. Active and passive earth pressures in contrast depend upon the soil's cohesion, *c*, and its angle of internal friction ϕ.

The angle *a*, Fig. 4, equals 45 deg. $+ \frac{\phi}{2}$; and ϕ, together with *c* and *K*, are determined by the triaxial shear or stabilometer tests.

PRESSURE CHAMBER SUGGESTED FOR USE IN THE PREPARATION OF SAMPLES

For stabilometer tests, cylindrical samples are encased in rubber sleeves clamped about bakelite disks (Fig. 5) which, with or without porous stones, are placed at the ends of the samples.

Samples of stabilized soil and embankment materials may be compacted in the apparatus shown in Fig. 6.

For tests using the closed system, compacted samples are placed in the rubber jackets with impervious disks at the bottom ends, and, after removal from the split cylinder mold, impervious disks are also placed at their upper ends. The clamps are adjusted and threaded studs are screwed into the bottom disks as shown in Fig. 7 (assembly B). This assembly can also be used for testing undisturbed samples at their natural moisture contents. Studs afford means to fasten sample assemblies in the stabilometers, and threaded recesses in the top disks, for attachment to plungers of the stabilometers.

Assembly G (Fig. 7) is suggested for use in determining permeabilities and capillarities of samples by application of water through the porous stone and tube in the bottom disk which furnishes a connection with the burette.

An apparatus, similar to that in Fig. 8 with a plain blank top, is usable in the pre-testing of samples for consolidation and swell. See also Rendulic (**23**) and Jürgenson (**7**). Rise of water

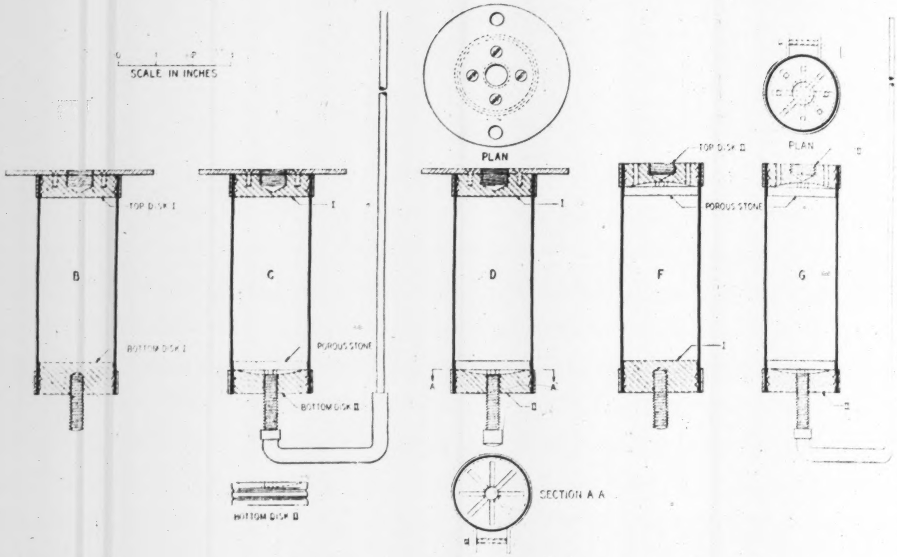

0 1 2 3
SCALE IN INCHES
TOP DISK I
B
BOTTOM DISK I
I
C
POROUS STONE
BOTTOM DISK II
BOTTOM DISK II
PLAN
I
D
A
A
II
SECTION A A
II
TOP DISK II
POROUS STONE
F
I
PLAN
G
II

FIG. 7.—Assemblies Showing Porous Stones and Disks Placed at Ends of Samples.

in the burette, assembly *C*, discloses the speed and amount of consolidation of samples at the applied air pressures; and drop of water in the burette indicates their swell. Metal guides attached to the top disks are to prevent tilting of samples during such tests.

At the conclusion of the preliminary tests, all spaces in porous stones, disks, and tubes at the bottoms of assemblies *C* and *G* are filled with water. Disconnecting the burettes and capping the tubes and, in the case of assembly *G*, replacing the perforated top disk with an impervious one, completes the change to assembly *D* (Fig. 7).

The Closed System:

Figure 9 is a diagram of a pressure chamber and sample assembly which is usable in the closed system of test. A nut on the tube fastens the assembly *D* to the chamber. A similar nut on the threaded stud, assembly *B*, serves a similar purpose.

Attaching one end only of sample

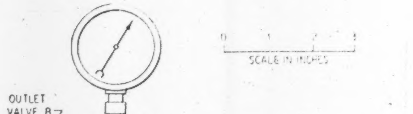

0 1 2 3
SCALE IN INCHES
OUTLET VALVE B
THREE ASSEMBLY BOLTS
BURETTE
TRANSPARENT CYLINDER
SAMPLE ASSEMBLY C
THREADED INTO BASE CHANNEL
GASKET
GASKETS

FIG. 8.—Pressure Chamber for Use in Consolidating Samples.

assemblies to the pressure chamber distinguishes the stabilometer, Fig. 9, as the free-rubber type used by Jürgenson, Delft Laboratories, Harvard University, Corps of Engineers, U. S. Army and the Bureau of Reclamation.

Harvard University and the Corps of Engineers suggest glycerine as a liquid satisfactory for use in the cylinder. To prevent leakage, Harvard utilized the stuffing box, Fig. 10, and the Corps of Engineers, the bronze bushing, Fig. 9.

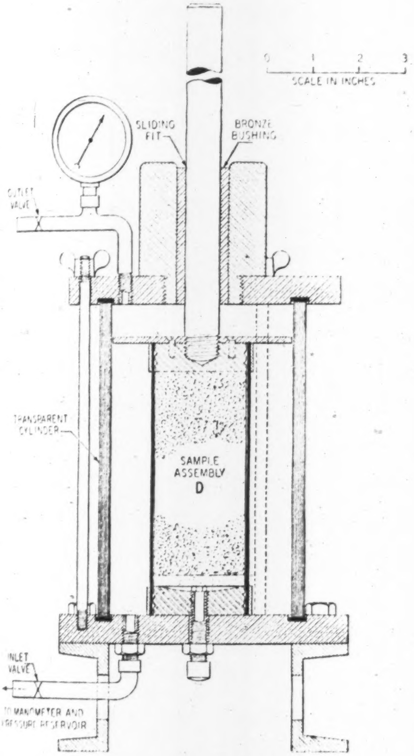

0
1
2
3
SCALE IN INCHES
SLIDING FIT
BRONZE BUSHING
OUTLET VALVE
TRANSPARENT CYLINDER
SAMPLE ASSEMBLY
D
INLET VALVE
TO MANOMETER AND PRESSURE RESERVOIR

FIG. 9.—Stabilometer of the Plunger Type.

Relative to the experience at Harvard University, John D. Watson (**12**) states: "It is absolutely essential that friction between this piston and the head be reduced to a negligible amount. At the same time it must be possible to maintain the hydrostatic pressure in the compression chamber constant while a test is in progress. A highly viscous fluid in the compression chamber would be far better than air because air under pressure is very difficult to confine without leakage. Glycerine was chosen because in addition to a high viscosity it is soluble in water and easy to wash off and clean up, and it does not attack rubber. The piston rod is jacketed with graphite steam packing, but the packing gland is screwed down so little that the piston rod will fall slowly under its own weight."

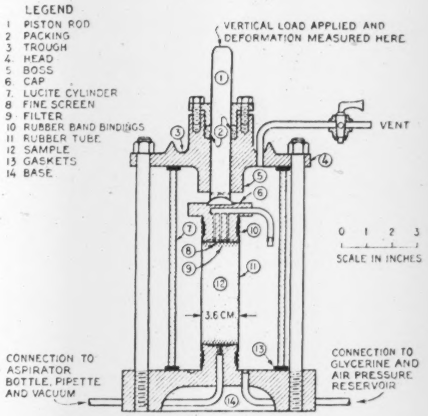

LEGEND
1 PISTON ROD
2 PACKING
3 TROUGH
4 HEAD
5 BOSS
6 CAP
7 LUCITE CYLINDER
8 FINE SCREEN
9 FILTER
10 RUBBER BAND BINDINGS
11 RUBBER TUBE
12 SAMPLE
13 GASKETS
14 BASE
VERTICAL LOAD APPLIED AND DEFORMATION MEASURED HERE
VENT
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬
⑭
0
1
2
3
SCALE IN INCHES
3.6 CM.
CONNECTION TO ASPIRATOR BOTTLE, PIPETTE AND VACUUM
CONNECTION TO GLYCERINE AND AIR PRESSURE RESERVOIR

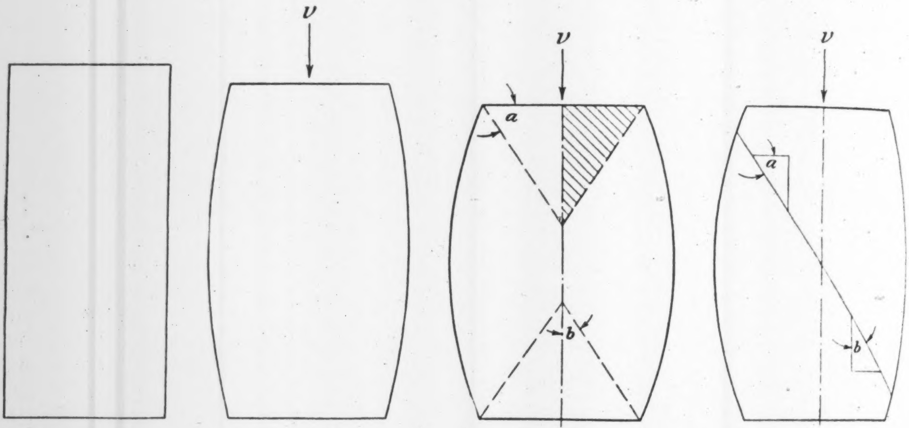
FIG. 10.—The Triaxial Compression Chamber.

Relative to the use of the bronze bushing, a report by the Corps of Engineers (**13**) states: "The hemp packing box has been eliminated and a bronze bushing substituted in its place. Experience has shown that friction is eliminated thereby and that leakage of glycerine even at high hydrostatic pressures is negligible."

Relative to the closed system, a report (**14**) on the Bureau of Reclamation's apparatus (Fig. 21) states: "The specimens are encased in thin-wall rubber tubes which clamp to metal end plates, thus keeping the water which completely fills the pressure cylinder from wetting them."

APPARATUS SUITABLE FOR VARIED PURPOSES

It is convenient to arrange the stabilometer in loading devices so that upward movement of the plunger is prevented while pressures within the chamber are increased to those selected for use in the tests. At particular lateral pressures thus provided, samples are compressed to failure by vertical pressures applied through the plunger.



(*a*) Before test. (*b*) Plastic yield. (*c*) Failure—shear cones. (*d*) Failure—shear plane.

FIG. 11.—Deformation of the Sample During Test.

Figure 11 illustrates the failure of a cylindrical sample. As the cylinder shortens it bulges first (Fig. 11 (*b*)) and then fails along the surfaces of slip (Fig. 11 (*c*) and (*d*)) which incline to the horizontal at the angle *a* shown in the stress diagrams, Fig. 4.

Tests on samples comprised of differently colored modeling clays disclosed the deformations, Fig. 12, undergone by the layers which had uniform thickness prior to test.

Reduction of the vertical pressure, accompanied by increase of lateral pressures, facilitates removal of samples from the chamber and container by reducing their diameters.

Analyses of test data by means of Mohr's circles of stress have been described in *Public Roads* (**24**). Common tangents which disclose the values of c and ϕ are drawn to arcs constructed from a knowledge of the vertical pressures, v, and the lateral pressures, l, on the sample at failure.

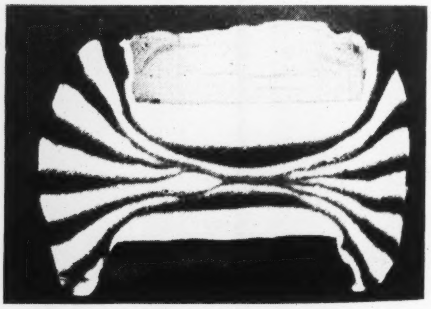


FIG. 12.—Deformation of a Clay Sample. The light and dark bands were of equal and uniform thickness before testing.

To illustrate, let the stress-strain relations, Fig. 13, represent data furnished by two tests. The cylinder tested at the lateral pressure l equals 100 lb. per sq. ft., failed at a vertical pressure v of 1046 lb. per sq. ft. The cylinder tested at l equals 500 lb. per sq. ft. failed at v equals 1900 lb. per sq. ft.

Figure 14 shows the graphical analysis. The full line at the top shows the relation between shear stress and normal pressure at failure of the cylinders. The straight broken lines show similar relations for strains less than the ultimate. The arcs have centers on the abscissa at a distance of $\frac{v + l}{2}$ from the origin; and radii to the same scale of $\frac{v - l}{2}$. This places the center of the smaller full line circular arc at the point corresponding to $\frac{1046 + 100}{2}$ lb. per sq. ft.; and makes its radius equivalent to $\frac{1046 - 100}{2}$ lb. per sq. ft.

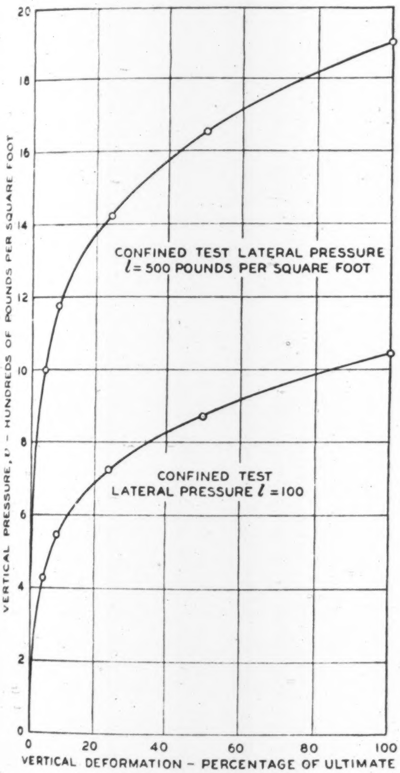


FIG. 13.—Stress-Strain Relations for Two Samples.

As the next step the relations of c and ϕ to deformations of the samples may be shown as published in the ASTM BULLETIN (25) and in the *Proceedings* of the Highway Research Board (22).

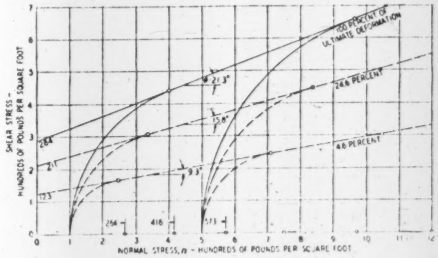


FIG. 14.—Graphical Analysis of Stresses in Cylinder.

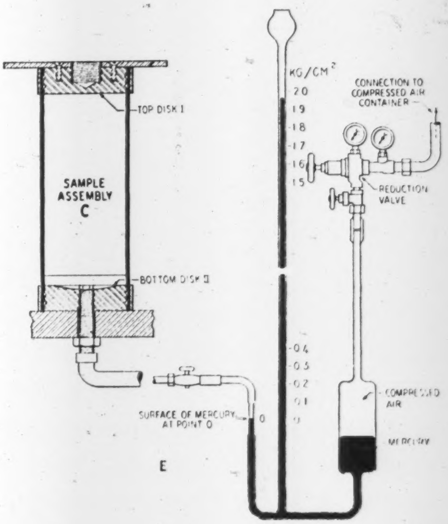

TOP DISK I
SAMPLE ASSEMBLY C
BOTTOM DISK II
KG/CM^2
2.0
1.9
1.8
1.7
1.6
1.5
0.4
0.3
0.2
0.1
0
CONNECTION TO COMPRESSED AIR CONTAINER
REDUCTION VALVE
COMPRESSED AIR
MERCURY
SURFACE OF MERCURY AT POINT O
O
E

FIG. 15.—Stabilometer Assembly with Special Manometer.

Use of sample assembly C with the special manometer, Fig. 15, permits the determination of pore pressures within samples during test. The special manometer has been discussed by Rendulic (**23**) and Hvorslev (**26**) elsewhere.

It may also be desired to determine the critical density of sands. This has been described by Arthur Casagrande (**27**) as that density at which a soil can undergo deformation or actual flow without volume change. See also Burmister (**28**). For this purpose assembly *C* is suggested.

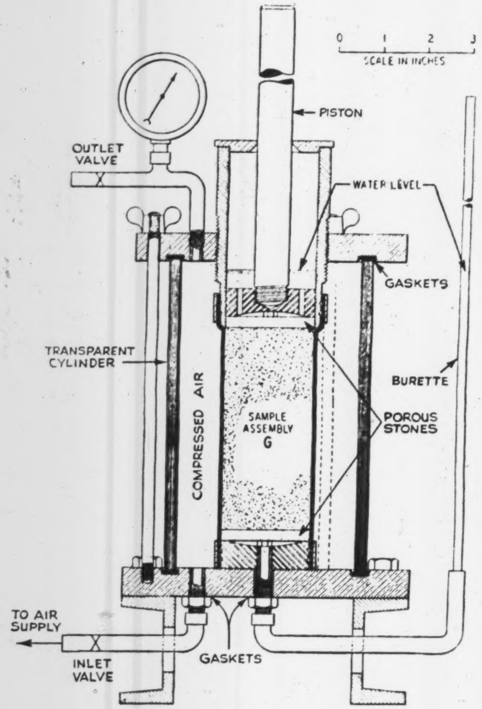

0
1
2
3
SCALE IN INCHES
PISTON
OUTLET VALVE
WATER LEVEL
GASKETS
TRANSPARENT CYLINDER
COMPRESSED AIR
SAMPLE ASSEMBLY G
BURETTE
POROUS STONES
TO AIR SUPPLY
INLET VALVE
GASKETS

FIG. 16.—Stabilometer Assembly of the Fixed Rubber Type.

And at times, tests on samples at the pore pressures of the pressure chamber may be required. Assembly *F* is suggested for this purpose.

THE COEFFICIENT *K* DETERMINED USING THE FIXED RUBBER TYPE

In the determination of coefficients of earth pressure at rest, lateral deformation of samples is confined to a minimum. For this purpose, the stabilometer, Fig. 16, is suggested. By the use of sample assembly *G* and at the discretion of the operator water may be applied directly to the top of the sample and by the connection through the lower disk, to the bottom of it.

The rubber sleeve of the sample assembly attached at both ends to the pressure chamber distinguishes the stabilometer, Fig. 16, as the fixed rubber type which has been used by Hveem, Buisman, Housel, Seibert and Palmer, Muir, the Shell Oil Co., and the Delft Laboratories (**14**).

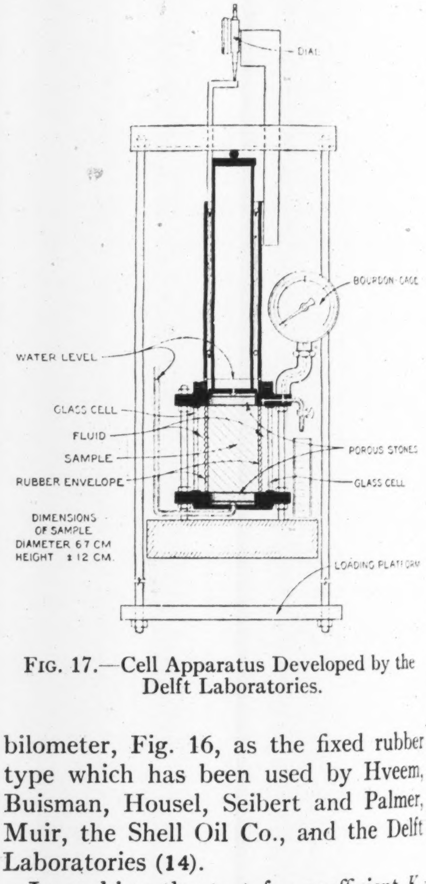

DIAL
BOURDON GAGE
WATER LEVEL
GLASS CELL
FLUID
SAMPLE
RUBBER ENVELOPE
POROUS STONES
GLASS CELL
DIMENSIONS OF SAMPLE
DIAMETER 6.7 CM
HEIGHT ± 12 CM.
LOADING PLATFORM

FIG. 17.—Cell Apparatus Developed by the Delft Laboratories.

In making the test for coefficient *K*, the chamber is completely filled with water and both outlet and inlet valves are closed to prevent escape of the water during test. The vertical pressure is then applied through the plunger, and

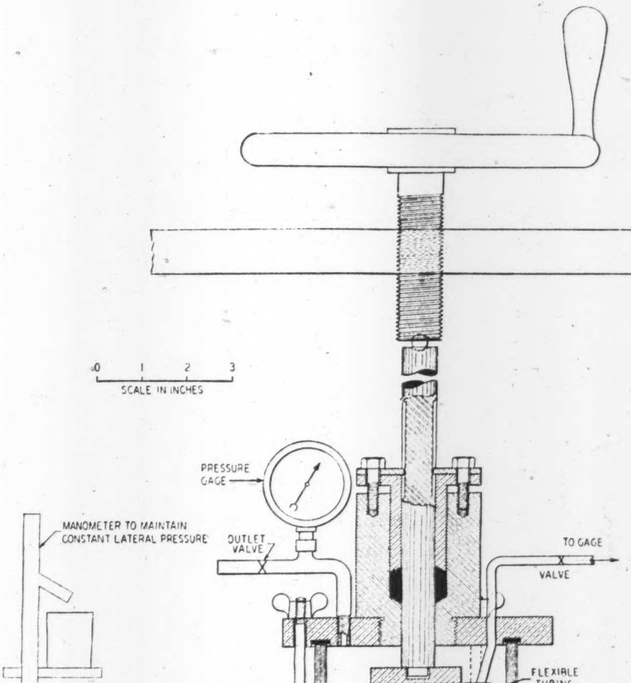

0 1 2 3
SCALE IN INCHES
PRESSURE GAGE
MANOMETER TO MAINTAIN CONSTANT LATERAL PRESSURE
OUTLET VALVE
TO GAGE
VALVE
FLEXIBLE TUBING
TRANSPARENT CYLINDER
BELLOWS
TO COMPRESSED AIR RESERVOIR
SAMPLE ASSEMBLY D
VALVE
NEEDLE VALVE
VALVE
VALVE

FIG. 18.—Stabilometer Assembly of the Bellows Type.

the gradually increasing lateral pressures are read from the gage.

Relations of *K* to moisture content of a soil are obtained from samples compacted at or consolidated to different moisture contents and tested at pressures within the range for which information is desired.

The stabilometer, Fig. 16, with confinement of liquid in the pressure chamber typifies also the cell apparatus, Fig. 17, used at the present time to test the soft undersoils for which Holland is noted. Thirty-eight of the devices were in use in the Delft Laboratories in the summer of 1938, and twenty-five more had been prepared for shipment to the University of Ghent, Belgium.

The testing procedure, described elsewhere (**14**), provides for the escape of the liquid in small amounts at a time from the chamber. This in turn causes increasing shear resistance to be developed as the soil deforms. Its unique feature is the testing of but one sample to obtain values of c and ϕ of an undisturbed soil at its natural moisture content. For shear tests of the same soil at lower moisture contents, samples are first consolidated in the stabilometers.

The long period of time required for this makes it advisable to preconsolidate the samples in the separate chamber, Fig. 8.

The impervious top disk of the sample, assembly *C*, would then be replaced by the porous stone and perforated disk, assembly *G*, and the rubber sleeve slipped over and clamped about the metal extension as shown in Fig. 16.

The selection of the type of stabilometer depends primarily upon the size of the samples to be tested, pressures to be used during test, laboratory facilities and personal preferences as to the use of air or liquid in the pressure chamber.

Sample Dimensions.—To insure that planes of rupture intersect the sides of samples, their heights should be at least twice their diameters. A diameter of 2 in. is satisfactory for soil which passes sieve No. 10.

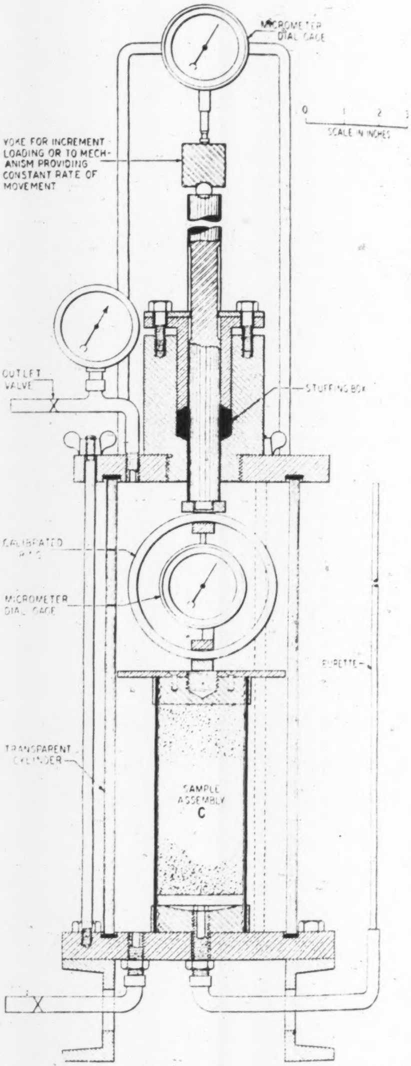

MICROMETER DIAL GAGE
0 1 2 3
SCALE IN INCHES
YOKE FOR INCREMENT LOADING OR TO MECHANISM PROVIDING CONSTANT RATE OF MOVEMENT
OUTLET VALVE
STUFFING BOX
CALIBRATED RING
MICROMETER DIAL GAGE
BURETTE
TRANSPARENT CYLINDER
SAMPLE ASSEMBLY C

FIG. 19.—Stabilometer Assembly of the Ring Type.

Samples with larger sized particles require larger diameters. Hveem has found a diameter of 4 in. satisfactory for certain types of bituminous road surfacings, and the Reclamation apparatus is suitable for testing samples up to 6 in. in diameter by 16 in. long.

Chamber Walls.—Apparatus of the size illustrated in Figs. 8, 9, 16, 18, and 19, provides for the testing of samples 2 in. in diameter by 4½ in. high. For tests of such samples the use of transparent tubing for the outer shell of the pressure chamber is recommended, since, among other things, it provides desirable visual inspection of samples during test.

Use of glass for this purpose, Fig. 20, was proposed by Buisman in 1934 and it is still used in European laboratories. The transparent plastics used in this country are recommended as more suitable. Relative to experience with them at Harvard University the Watson report (**12**) states:

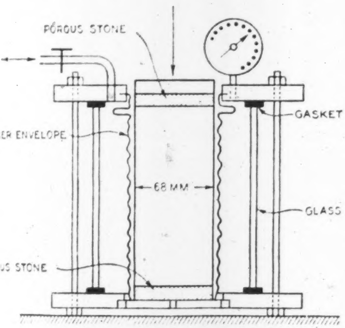


FIG. 20.—Cell Apparatus with Glass Cylinder Used by Buisman.

"This pressure chamber was designed for and has been successfully used under an internal pressure up to 10 kg. per sq. cm. [Plate B II-1 the accompanying Fig. 10] shows that it consists of a Lucite cylinder enclosed with rubber gaskets between a cast brass head and base."

For large samples and for the high pressures commonly used to test semirigid pavement surfacing materials, outer cylinders consisting of metal are used. The elaborate apparatus constructed by the Bureau of Reclamation is shown in Fig. 21. Relative to the latter's apparatus, their report (**14**) states:

"The loading equipment will develop and measure an axial load up to a maximum of 7500 lb. and deform specimens as much as 4 in."

Application of Load.—Some laboratories use testing machines for applying load to the samples and measuring their vertical deformations. Others make use of yokes, levers, or threaded plungers to apply the loads, and micrometer dials to measure the deformations.

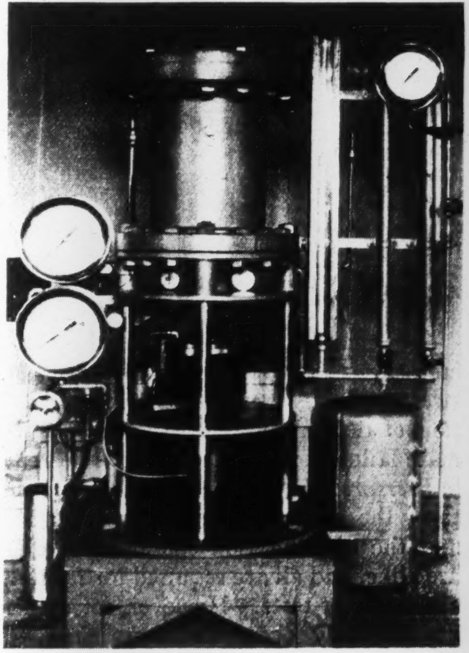


FIG. 21.—Stabilometer Used by the Bureau of Reclamation.

Figure 22 shows the testing machine used at Harvard University. The method using the threaded plunger is employed by Jürgenson, Hennes, the Bureau of Reclamation, and, in tests of unconfined cylinders, as shown in Fig. 23, by Burmister.

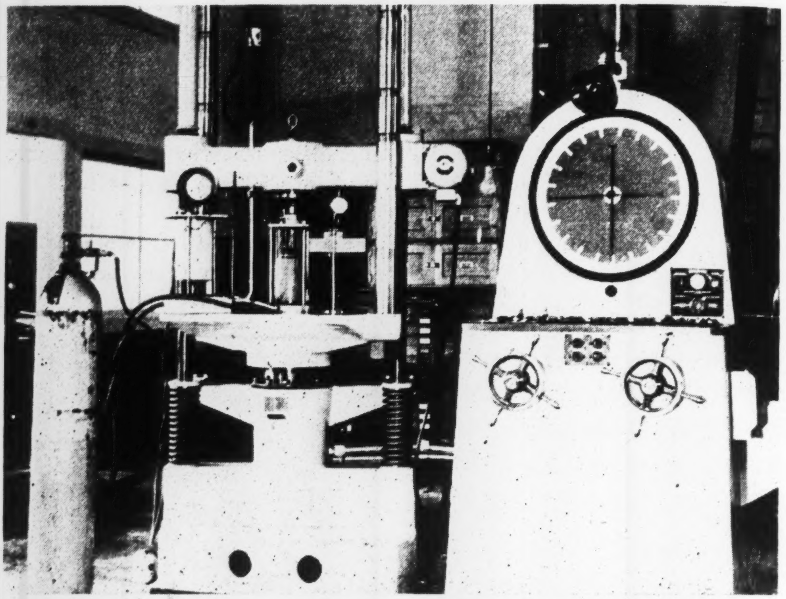


FIG. 22.—Apparatus Used in Making Triaxial Shear Test at Harvard University.

All methods are considered satisfactory. However, constant rate of strain methods facilitate the determination of deformations indicative of ultimate failure and are therefore preferred.

Pressure Chambers.—Except for their tops, the stabilometers, Figs. 9 and 16, and the consolidation chamber, Fig. 8, are alike, and all are required for routine stabilometer tests. However, for use in making only occasional tests the one base and cylinder with the three different tops should prove adequate. If the use of glycerine within the chamber or the possibility of leakage from it is considered objectionable, the apparatus, Figs. 18 and 19, can be substituted for the free rubber type, Fig. 9.

To make the chambers airtight, packing must be compressed enough to prevent frictionless movement of the plunger. Therefore, means within the chambers to measure vertical pressures applied to the samples is required.

FIG. 23.—Load Measurement by Calibrated Ring.

For this purpose use of a sylphon bellows (Fig. 18), or a calibrated ring (Fig. 19) is suggested. Jürgenson (**7**) placed a bellows inside the chamber and the Bureau of Reclamation (Fig. 21) have theirs on the outside. The calibrated ring has been used in direct shear tests at the Massachusetts Institute of Technology (**29**) and by Burmister (**14**) in unconfined cylinder tests as shown in Fig. 23.

Figure 18 illustrates the use of a manometer for controlling lateral pressures and the threaded plunger method of applying load. Manometers used in Jamieson's early experiments have been employed also in the Delft laboratories, and to supplement pressure gages in the control of low lateral pressures by the Bureau of Public Roads. Since provision is made for measuring applied vertical pressures, the threaded plunger is usable to apply constant rate of strain. Figure 19 illustrates also an arrangement for measuring vertical movements of the plunger when the loads are applied through yokes.

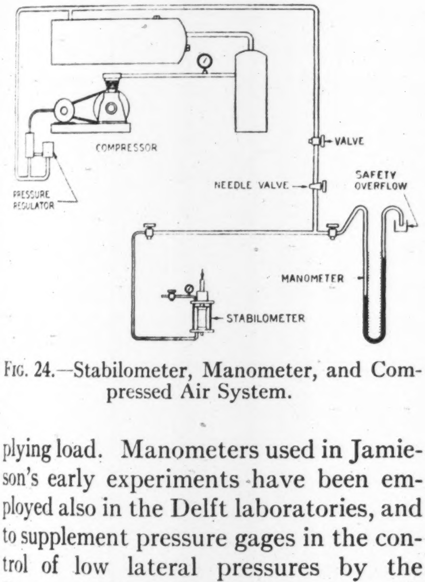


FIG. 24.—Stabilometer, Manometer, and Compressed Air System.

Chamber Pressures.—The air supply system used by the Public Roads Administration, Fig. 24, provides for pressures up to 125 psi. and a reservoir of 2 cu. ft. capacity. The Bureau of Reclamation's apparatus provides lateral pressures to a maximum of 200 psi. Constant pressures are maintained by means of a pressure control device which automatically starts and stops the compressor. For maintaining constant lateral pressures up to at least 10 psi., the manometer shown in Fig. 18 is a valuable supplement to the automatic pressure control device. For larger lateral pressures, the controlled pressure air reservoir is used.

CLOSED SYSTEM SUGGESTED FOR THE DETERMINATION OF c AND ϕ

Data furnished by direct shear tests illustrate advantages of the "closed" as compared with the "open" system of test. Relations of s to n, Fig. 25, were obtained from data furnished by open system tests, published elsewhere (**30**). Samples placed between porous stones and consolidated to equilibrium at the moisture contents indicated were sheared at several normal pressures up to and including the consolidation pressure.

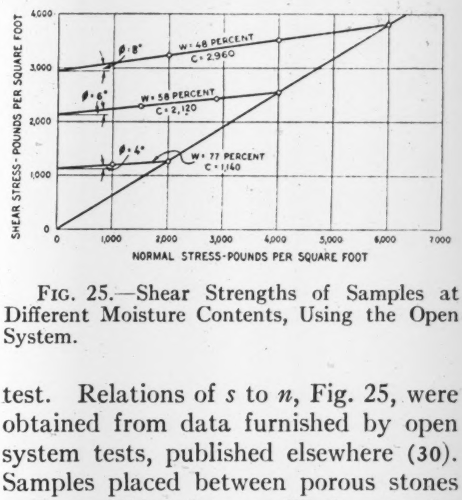


FIG. 25.—Shear Strengths of Samples at Different Moisture Contents, Using the Open System.

To illustrate deficiencies of the data, Fig. 25, let it be assumed that an embankment which on completion will produce a pressure of 6000 lb. per sq. ft. is to be constructed on the soil at a natural moisture content of 77 per cent. At this moisture content and for pressures up to *n* equals 2000 lb. per sq. ft., *c* equals 1140 lb. per sq. ft. and ϕ equals 4 deg. Consolidation by embankment pressure of 6000 lb. per sq. ft. can be expected ultimately to reduce the soil's moisture content to 48 per cent; and at this moisture content it has for normal pressures up to 6000 lb. per sq. ft., values of *c* and ϕ equal 2960 lb. per sq. ft. and 8 deg., respectively.

Depending on the relative speeds of embankment construction and consolidation of the undersoil, excessive pore pressures may be produced which make failure of the undersoil imminent. In such cases it was considered advisable (**31**) to make use of standpipes inserted in the undersoil so that the speed of its consolidation could be observed.

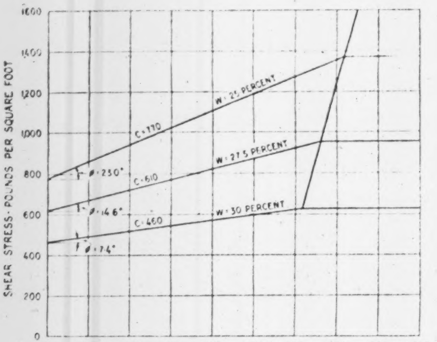


FIG. 26.—Shear Strengths of Samples at Different Moisture Contents, Using the Closed System.

Information required for the intelligent use of such standpipes necessitates extension of the data, Fig. 25, to include relations of *s* to *n* up to normal pressures of 6000 lb. per sq. ft. for the samples which contain both 77 and 58 per cent moisture.

To obtain the supplementary data, shear tests must be made on samples at normal pressures greater than the consolidation pressures, and for this purpose the open system as used in direct shear tests is impractical, because of the rapid speed at which the relatively thin samples used in such tests consolidate.

Therefore, the closed system which furnishes the complete data, Fig. 26, is deemed more suitable.

Determination of the pressures at which the relations of *s* to *n* change, as shown in Fig. 26, is especially important since they indicate the upper limit of stresses that can be applied without causing the angle ϕ of the soil at a particular moisture content to become reduced.

Thus, the soil, Fig. 26, at a moisture content of 30 per cent has *c* equals 460 lb. per sq. ft. and ϕ equals 7.4 deg. for normal pressures up to the limit of *n* equals 1230 lb. per sq. ft. At normal pressures greater than *n* equals 1230 lb. per sq. ft., the shear stress became constant at 620 lb. per sq. ft.

Change of the soil's character with increase of its ratio of free water to film moisture has long been recognized. As discussed elsewhere (**22**) this ratio may be increased in two ways as follows:

1. By increasing the moisture content of soil at constant pressure.
2. By increasing the pressure on soil at constant moisture content.

It has been explained in *Public Roads* (**32**) that increasing the moisture content of semirigid soils at constant pressure increases the ratio of free or lubricating water to the more viscous film moisture, until at moisture contents above the plastic limit, the ratio becomes large enough to give soils the properties of plastic instead of semirigid materials. In the same publication, data from unconfined cylinders, which are triaxial shear tests with the lateral pressure *l* = 0, showed that at moisture contents above the "critical" which for plastic soils is the plastic limit, the samples exhibited little or no additional strength with increasing deformations, above the resistance they had at the plastic limit.

Increasing the pressure (**33**) reduces thicknesses of adsorbed films and therefore in soil maintained at constant moisture content, causes the ratio of lubricating to film moisture to be increased as effectively as raising the moisture content of soil at constant pressure.

The effect of pressure increase to reduce the lower limit of moisture contents of soil in the plastic state has been reported (**34**). Therefore, the breaks in the relations of s to n, as shown, are explained on the basis of film phenomena, and for the particular pressures at which they occurred, the respective moisture contents are considered as the critical moisture contents.

What relation, if any, these critical moisture contents bear to pressures required to consolidate the soil has not been disclosed by investigations of the consolidation characteristics of this soil made to determine whether any such relation exists.

From the complete data, Fig. 26, one obtains relations of moisture content to c and ϕ, the pressures at which the soil becomes plastic, and the pore pressure. From such relations and by means beyond the scope of this report, usable safe values of c and ϕ can be selected with respect to the speed of consolidation as indicated by the elevations of water in the standpipes (**35**) inserted in soft undersoils.

SUMMARY

The foregoing presents essential features of what seem to be the most promising methods of making stabilometer tests. It is recognized at the same time that compressed air as well as liquid may be used to determine the coefficient K and also that the open system may be utilized to evaluate c and ϕ. Samples used in stabilometer tests have heights of possibly ten times the thicknesses of samples tested in direct shear and therefore, according to the theory of consolidation, consolidate only one one-hundredth as rapidly and in consequence have considerably less error due to change of moisture content during test in the open system. Such tests made in the Delft Laboratories by what Professor Huizinga terms the quick method (**14**) are considered satisfactory by him for relatively impermeable soils.

It was the consensus at the Eighteenth Annual Meeting of the Highway Research Board (**36**) "that the triaxial compression or stabilometer device is the most useful shearing method and despite all obstacles it is proposed to obtain and use complete stress deformation diagrams in connection with highway problems."

Among the advantages provided by this method of test may be listed the following:

1. Samples have the shape common to usual compaction, permeability, and sampling devices.
2. Properties of samples as a whole instead of only a fraction thereof can be determined.
3. Samples of embankment materials may be tested as compacted and after they have been tested for permeability and capillarity.
4. Samples of road materials may be tested as prepared and after their subjection to saturation freezing and thawing, and the like.
5. Samples of foundation soils may be tested in their natural undisturbed state and at several other moisture contents to the end that complete relations of moisture content to c, ϕ, and pore pressure is provided.

6. Samples may be tested at pressures similar to those that soils and roads are expected to resist under service conditions.

7. Uniform pressures are applied on the surfaces of samples.

8. All stresses on the sample are measured and may be varied or kept constant as desired.

9. Both the vertical and horizontal deformations can be controlled and are measurable.

10. The data are usable in theories of design.

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A TRIAXIAL COMPRESSION APPARATUS FOR THE DETERMINATION OF THE STRESS-DEFORMATION CHARACTERISTICS OF SOILS

BY JOHN D. WATSON[1]

In 1937 the United States Engineer Office in Boston, Mass., was confronted with the necessity of constructing out of a fine silty sand a large earth dam for flood control purposes. The safety of an embankment constructed of such a material was a question deserving special consideration since Casagrande had shown[2] that a large mass of fine-grained soil is inherently unstable unless it is compacted below the critical void ratio. When the construction of this dam at Franklin Falls, N. H. was first proposed, the question immediately arose as to how densely this material should be compacted to be safely below the critical void ratio. After an extensive investigation by means of direct shear tests which did not lead to a satisfactory solution, it was decided to adapt the principle of triaxial compression to the study of this problem. But before the triaxial apparatus is described, let us first consider the character of the volume changes which occur in sands subjected to shearing, and the reasons why the direct shearing test is unsatisfactory for measuring either the magnitude of these volume changes or the shearing strength of the soil.

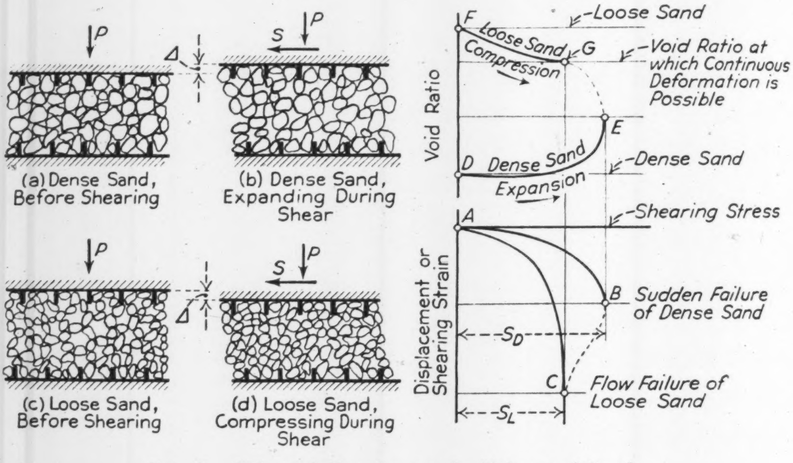
P
S
Δ
(a) Dense Sand, Before Shearing
(b) Dense Sand, Expanding During Shear
(c) Loose Sand, Before Shearing
(d) Loose Sand, Compressing During Shear
Void Ratio
F
Loose Sand
Loose Sand Compression
G
Void Ratio at which Continuous Deformation is Possible
E
D
Dense Sand Expansion
Dense Sand
A
Shearing Stress
Displacement or Shearing Strain
B
Sudden Failure of Dense Sand
S_D
C
Flow Failure of Loose Sand
S_L

FIG. 1.—Effect of Shearing on the Volume of Sands.

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[1] Research Fellow in Soil Mechanics, Graduate School of Engineering, Harvard University, Cambridge, Mass.

[2] Arthur Casagrande, "Characteristics of Cohesionless Soils Affecting the Stability of Slopes and Earth Fills," *Journal*, Boston Soc. Civil Engrs., Vol. XXIII, January, 1936, pp. 17–22.

Volume Changes in Cohesionless Soils Under Load:

In the course of a long program of research on the shearing resistance of soils, carried out at the Massachusetts Institute of Technology (1929 to 1932), Casagrande[3] observed that all soils change in volume when subjected to shearing stress at a constant vertical load. A sand in a loose state decreases in volume during a direct shear test, while the same sand in a dense state increases in volume under the same conditions.

These facts he illustrated diagrammatically as shown in Fig. 1. Structurally the loose sand is composed of many small arches. These arches break down when subjected to shearing stress and the density of the mass increases. In order that deformation occur in a dense sand the closely interlocked grains must expand so that the grains can roll over one another. If this did not take place, some grains must be sheared in two. The former occurrence is more likely under a moderate normal load.

In Fig. 1 the horizontal movement and the volume change are plotted as ordinates and the shearing stress as abscissa. In a loose sand the shearing stress increases gradually from A to C, the void ratio decreasing from F to G at the same time. At this void ratio G, continuous movement is possible at a constant shearing resistance S_L. The failure of the loose sand is a plastic flow rather than a rupture.

If this same sand be compacted into a dense state, that is, such that its void ratio corresponds to D instead of F, then the amount of horizontal movement for the same stress in an identical test is much less. For the first half of the test there is no appreciable change in volume, but expansion begins shortly thereafter and continues at a rapidly increasing rate until failure occurs. The failure, which occurs as a sudden rupture, is followed by a decrease in the shearing stress, rapid horizontal movement, and some further volume expansion. The total volume expansion is of such magnitude that the same critical void ratio G as before is reached, at which continuous movement at a constant stress S_L is possible.

Disadvantages of the Direct Shear Test:

The above observations were all made on shear tests performed with a rectangular shearing frame. This type of apparatus, however, is subject to the following errors which cannot be eliminated:

1. The stress distribution of the normal load is not uniform as it is commonly assumed.
2. The ratio of the perimeter of the frame to the area is different for different sizes of frames. This boundary effect is, therefore, more pronounced in the smaller frames, and values of the shearing strength determined in one size of frame differ from those obtained in another size frame.
3. Progressive failure, beginning at the ends or near the teeth of the gratings (if used), occurs in dense sands. Thus the measured value of the shearing strength is an average value rather than the maximum.
4. The horizontal movement is indicated by an extensometer. This is no measure of the strain, nor can the actual strain be determined.
5. As soon as any horizontal movement occurs, the area begins to decrease.
6. Because of the small mass of soil used in a direct shear test, both the volumetric and gravimetric measurements must be precise for an accurate

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[3] A. Casagrande and S. G. Albert, "Research on the Shearing Resistance of Soils," Massachusetts Institute of Technology Report, unpublished.

determination of the void ratio. Since the expansion or contraction of the soil is measured in one direction only, the magnitude of the volume changes during a shear test is qualitative rather than quantitative. Any tilting of the upper frame may give an entirely erroneous conception of the magnitude of the volume change.

Early Development of Triaxial Apparatus:

The triaxial compression tests on marble by von Karman[4] are the earliest tests of this type to which any reference can be found. Many theoretical analyses, among them the notable one by Mohr,[5] had already been made. An outstanding investigation[6] of the behavior of concrete when subjected to triaxial compression was carried out at the University of Illinois in 1927.

In 1928 Ehrenberg developed a triaxial consolidation apparatus at the Preussiche Versuchsanstalt für Wasserbau und Schiffbau in Berlin. Casagrande designed a triaxial compression apparatus for soils at the Massachusetts Institute of Technology in 1930. The principal fault of this apparatus was the necessity of a tight packing gland which produced too much friction on the piston. Subsequently Rendulic[7] designed and used a triaxial compression apparatus for testing cohesive soils. He had a viscous oil on top of the water which surrounded the sample to reduce the leakage around a loosely fitting piston. The interior of the sample was connected through a wye either to a manometer or to a burette. In this way he could measure the pressure in the pore water of the clay or the amount of water which would be squeezed out under compression.

In 1937 Casagrande suggested to the author that such a viscous pressure fluid as glycerin would permit the use of a practically frictionless piston and the leakage around the piston would be insignificant. In addition to its high viscosity glycerin has the further advantage that, being soluble in water, it is easy to wash off and clean up, and it does not attack rubber. Following the original design of Casagrande and using glycerin as the fluid in the pressure chamber, the author had built a triaxial compression apparatus which would maintain a constant pressure for several hours and in which the friction did not exceed 2 per cent and averaged less than 1 per cent of the load. It was

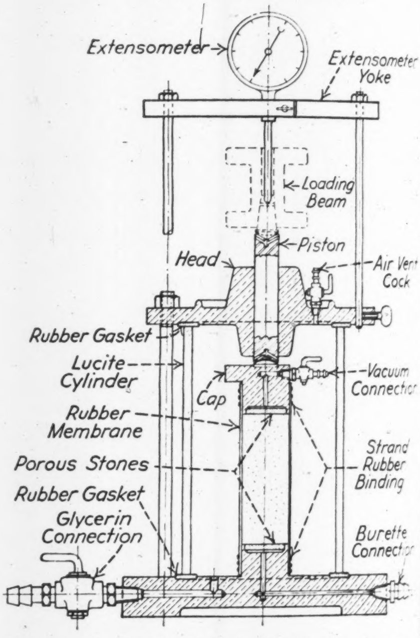

FIG. 2.—Sectional Sketch of Triaxial Compression Chamber.

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[4] Th. von Karman, "Festigkeitversuche unter allseitiger Druck," Verein deutscher Ingenieure Verlag, Berlin (1912).

[5] Otto Mohr, "Welche Umstände bedingen die Elastizitätsgrenze und den Bruch eines Materials," *Zeitschrift* des Vereines deutscher Ingenieure, Band 44, pp. 1524–1530, 1572–1577 (1900).

[6] F. E. Richart, A. Brandtzaeg and R. L. Brown, "A Study of the Failure of Concrete Under Combined Compressive Stresses," *Bulletin No. 185*, Engineering Experiment Station, University of Illinois, Urbana, Ill. (1927).

[7] Leo Rendulic, "Ein Grundgesatz der Tonmechanik und sein experimenteller Beweis," *Der Bauingenieur*, Heft 31/32 (1937).

then necessary to develop and perfect a technique of testing for cohesionless soils such that the following initial steps could be successfully accomplished: (1) the soil sample must be packed into a rubber tube, (2) it must be sealed air-tight and held under a vacuum until the hydrostatic pressure can be applied through the glycerin, (3) its weight and total volume must be known for computation of the void ratio, and (4) it must be completely saturated with water. When this is done, the pressure chamber is assembled around the sample, and the glycerin is pumped in by air pressure. Then a vertical load is applied to the sample by the piston until failure occurs.

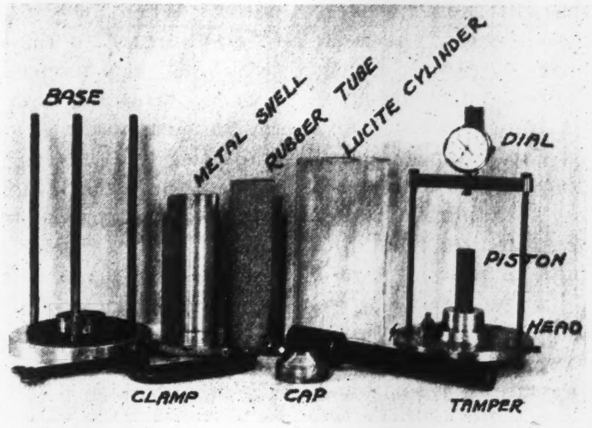
BASE
METAL SHELL
RUBBER TUBE
LUCITE CYLINDER
DIAL
PISTON
HEAD
CLAMP
CAP
TAMPER

FIG. 3.—Photograph of Dismantled Triaxial Compression Chamber.

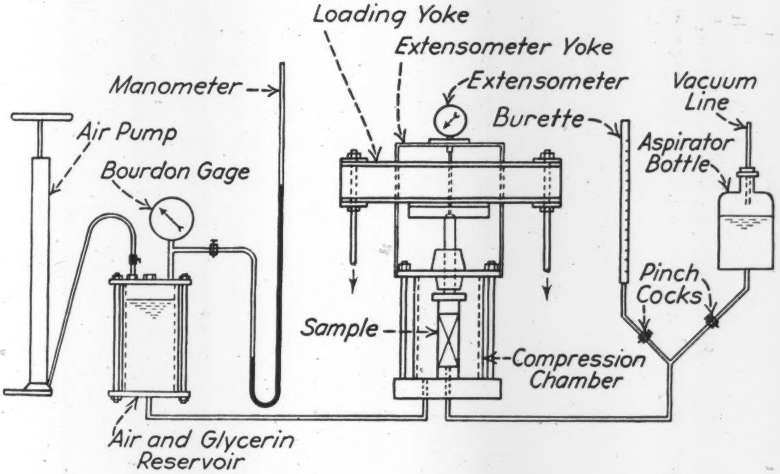
Loading Yoke
Extensometer Yoke
Extensometer
Manometer
Vacuum Line
Burette
Air Pump
Aspirator Bottle
Bourdon Gage
Pinch Cocks
Sample
Compression Chamber
Air and Glycerin Reservoir

FIG. 4.—Diagrammatic Sketch of Apparatus.

Description of the Present Triaxial Compression Apparatus:

A cross-sectional sketch of the compression chamber of the present apparatus is shown in Fig. 2. The circular base has a pedestal in its center on which the soil sample is mounted. The rubber membrane is sealed to this pedestal, and also to the cap, by five or six turns of strand rubber bound very tightly. The wall of the compression chamber is a cylinder of Lucite, a transparent plastic, and soft rubber gaskets are provided at each end. The head is merely a circular plate with a long boss on both its upper and under sides, an air vent, and a trough to catch any glycerin leakage. The piston is lapped in to a loose sliding fit. The length of the bosses reduces to a minimum any tendency for the piston to bind and increases the length of path of escape for the glycerin.

The lower end of the piston has a conical counterbore, which is opened to the hydrostatic pressure by a small hole drilled toward the axis through the piston rod. This conical counterbore fits a steel hemisphere which is pressed into the sample cap. The contact between these surfaces is a ring which insures a concentric application of the load. The top of the cap is flat so that the cap can easily be leveled by means of a spirit level when it is originally placed.

A photograph of the triaxial compression chamber (dismantled) is shown in Fig. 3, while in Fig. 4 is shown a diagrammatic sketch of the whole apparatus. After binding a cylindrical rubber membrane to the base, a metal shell (see Fig. 3) is clamped around the rubber membrane for molding and supporting the sample of cohesionless soil which is to be packed into the rubber. When the cylinder is filled, the cap is set on, leveled, and the membrane is bound to the cap just as it was to the base.

A vacuum is applied at the top of the sample through the petcock in the cap. The sample will then stand erect when the metal shell is removed so that measurements of the sample diameter and height can be taken. Having found the volume, and knowing the dry weight of soil which went into the sample as well as the specific gravity of the solid matter of the soil, the void ratio, or the porosity, can readily be computed. When the pinch cock (see Fig. 4) on the tube to the aspirator bottle (which is also under a vacuum) is opened, water will flow by gravity into the bottom of the sample, completely saturating it. After this is accomplished, the petcock in the cap is closed and the vacuum hose removed from it.

The Lucite cylinder and rubber gaskets are then placed in position and the head bolted down. The air pressure is built up in the air and glycerin reservoir, and glycerin flows into the compression chamber. When the compression chamber is completely filled with glycerin, the air pressure can be set at any desired value. Pressures of less than two atmospheres are measured by a mercury manometer, higher pressures by means of a Bourdon gage. When the glycerin which surrounds the sample is under pressure, the vacuum of the interior of the sample can be released. The pinch cock to the burette (Fig. 4) is then opened and the one to the aspirator bottle closed.

In the usual type of test the sample is loaded vertically, the lateral pressure in the glycerin being maintained constant. The data consist of observations on the load, the deformation, and the volume change. When the water level in the burette rises, water is being squeezed out of the sample, the volume of the sample decreasing. Contrarily, when the water level in the burette goes down, the sample is taking in water and increasing its volume. The vertical load can be applied by any testing machine. However, a constant strain

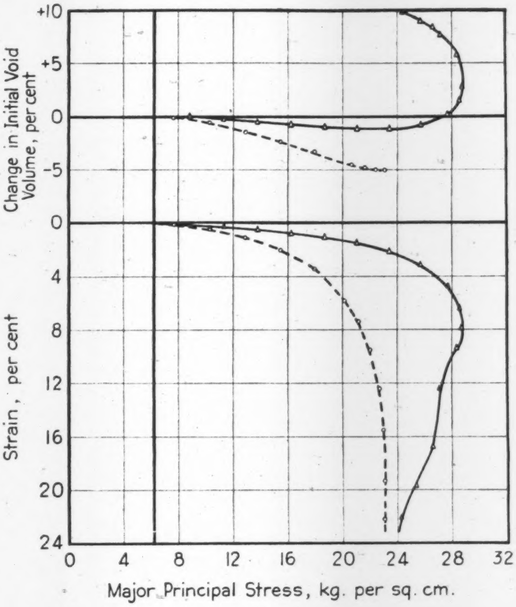

FIG. 5.—Typical Stress-Strain Curves for Sands.

INITIAL CONDITIONS:

$\sigma_1 = \sigma_3 =$ 0.95 kg. per sq. cm.

		Loose		Dense
V_v	=	321 cu. cm.	=	298 cu. cm.
V_s	=	417 cu. cm.	=	519 cu. cm.
e_o	=	0.770	=	0.573

AT START OF TEST:

$\sigma_1 = \sigma_3 =$ 6.32 kg. per sq. cm.

		Loose		Dense
V_v	=	308 cu. cm.	=	294 cu. cm.
V_s	=	417 cu. cm.	=	519 cu. cm.
e_p	=	0.737	=	0.565

FAILURE:

		Loose		Dense
		Uniform bulbing		Shear failure
σ_1	=	23.15	=	28.70 kg. per sq. cm.
δ_m	=	20.1 per cent	=	7.9 per cent
Δ_F	=	−16.7 cu. cm.	=	+8.9 cu. cm.
σ_1/σ_3	=	3.66	=	4.54
ϕ''	=	34°50′	=	39°50′

where:

σ_1 = major principal stress, axial for all tests herein referred to.
σ_2 = intermediate principal stress.
σ_3 = minor principal stress.
$\sigma_2 = \sigma_3$ for this particular design of triaxial apparatus.
V_v = volume of voids in a sample.
V_s = volume of solid material in a sample.
e_o = initial void ratio, i.e., the void ratio under a vacuum of approximately one atmosphere.
e_p = void ratio at the start of the test.
δ_m = unit strain corresponding to maximum stress in per cent of the height of sample at start of the test.
Δ_F = magnitude of volume change at failure in cubic centimeters. Positive values indicate volume expansion, negative values volume decrease of sample.
ϕ = angle of internal friction.
ϕ' = angle of obliquity.
ϕ'' = angle of a line passing through the origin and tangent to the stress circle of Mohr. This angle ϕ'' equals ϕ for cohesionless soils when the envelope to the stress circles is a straight line.

testing machine is to be preferred because at failure there is a rapid change in volume and deformation with either no change in load, or perhaps a decrease in load. The point of maximum stress is assumed to be the point of failure in all tests. A more complete description of the apparatus and the procedure for its use have been given elsewhere.[8]

Typical Test Results:

The application of the triaxial compression apparatus to the determination of the stress-deformation characteristics of cohesionless soils can best be explained by an examination of some typical test results.

Volume changes from the test observations are expressed in percentage of the initial void volume—positive for volume increase and negative for volume decrease. The strain is computed from the original length of the sample. The following correction is made for the area increase of the sample:

$$\text{Corrected area} = \frac{\text{original area}}{1.0 - \text{strain}}$$

The unit vertical stress in the sample is computed for each increment of load (or strain) by adding to the external pressure the unit hydrostatic pressure.

A plot of these data for two tests on a medium-fine sand taken from the shell of an earth dam is shown in Fig. 5. These may be considered typical for cohesionless materials. In the test shown by dash lines the sample was loose. This sample continuously reduced in volume under load. After reaching a maximum stress and a minimum volume, this sample continued to deform without any further increase in load or change in volume. There was no evidence of rupture. The sample failed by plastic flow which was also indicated by the uniform bulging, as shown in Fig. 6, left.

In the second test (Fig. 5, solid lines) the sample was dense. The sample reduced slightly in volume until the load was 80 per cent of the maximum. Then the sample began to expand rapidly. Soon after reaching the maximum stress, shearing planes began to appear and the load continued to fall off until it was less than 90 per cent of the maximum. At this point the volume change practically ceased and the sample continued to deform with no further change in load. This sample after failure is shown in Fig. 6 on the right.

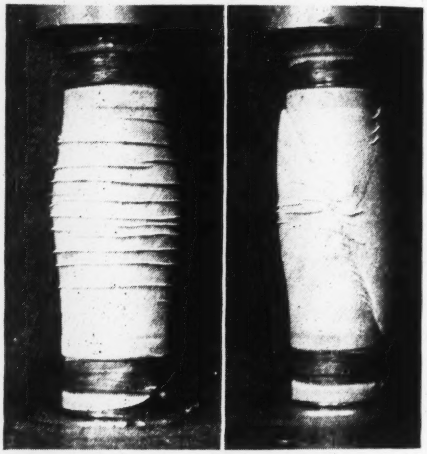

FIG. 6.—Types of Failure: Plastic Flow in Loose Sand (Left); Rupture in Dense Sand (Right).

One very striking result of these and many other tests is the greater strength and the greater rigidity of the dense sands as compared to the same sands in a loose state. After failure the stress at which the two samples in Fig. 5 continued to deform was approximately the same. The loose sample had decreased uniformly in volume. The dense sample had increased in volume sharply, but the major part of this increase was in the zone in which the shearing planes appeared. For this reason it cannot be proven from the magnitude of the volume changes that the two samples did reach the same void ratio after failure. It is logical to believe, however, that this did occur.

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[8] "Compaction Tests and Critical Density Investigation of Cohesionless Materials for Franklin Falls Dam," privately printed by the U. S. Engineer Office at Boston, Mass.

Most significant is the fact that, before reaching failure, the loose sample decreased in volume and the dense sample increased. How this phenomenon can affect the stability of earth embankments has been explained by Casagrande (p. 20).[2] That void ratio which at failure is neither larger nor smaller than it originally was before application of load, he has called the critical void ratio. It is not easy to prepare a sample the void ratio of which corresponds to this critical value. Nevertheless, by performing a series of tests at the same lateral pressure and varying only the initial void ratio, an approximately straight-line relationship is found to exist between the void ratio and the percentage of volume change at that particular pressure (see Fig. 7).

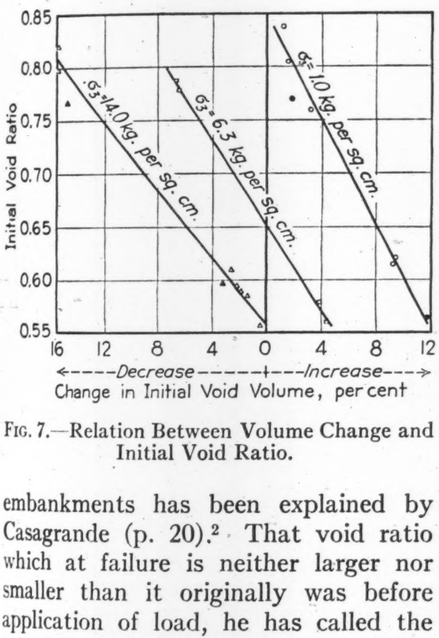


FIG. 7.—Relation Between Volume Change and Initial Void Ratio.

When the lateral pressure is increased, the amount which a loose sample will contract is also increased, and the amount which a dense sample will expand is reduced. The critical void ratio is, therefore, not a constant but varies with the magnitude of the lateral pressure. However, the amount of this variation differs with different materials. For Ottawa standard sand and for another very uniform sand derived from the St. Peter sandstone of Minnesota, this variation in the amount of expansion with lateral pressure was found to be so small that it was scarcely apparent. A grain-size distribution curve for each of the materials herein referred to is shown in Fig. 8.

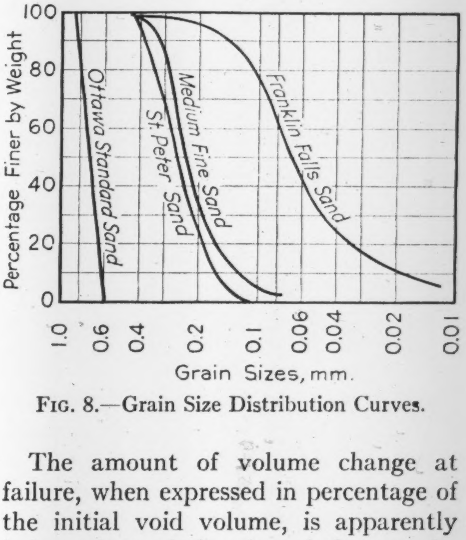


FIG. 8.—Grain Size Distribution Curves.

The amount of volume change at failure, when expressed in percentage of the initial void volume, is apparently independent of the size of the sample. This is seen by an examination of Fig. 7. Those points indicated by open symbols were observed on samples approximately $2\frac{3}{4}$ in. in diameter and 8 in. high. The points indicated by solid symbols were observed on small-size samples approximately $1\frac{3}{8}$ in. in diameter and 4 in. high. The latter has a volume only one-eighth as large as the former.

Shearing Strength of Cohesionless Materials:

According to Mohr's[5] rupture hypothesis, the angle of internal friction ϕ is represented by the slope of the tangent at a given point on the rupture line. When the rupture line, which is assumed to be coincident with the envelope to Mohr's circles of stress, is curved, then the angle of internal friction will vary with the magnitude of the principal stresses. Let us assume a curved rupture line *OR*, Fig. 9. For a given point *A* on this rupture line the tangent *AB* at this point has a slope ϕ which is equal to the angle of internal friction. If we connect point *A* with a straight line to the origin, we arrive at the obliquity ϕ' for that particular combination of normal and shear stress. Finally, if we draw through point *A* Mohr's circle of stress which represents the stress condition at the point of failure (that is, a circle to which the rupture line *OR* is tangent), and draw a tangent *OC* to this circle such that it passes through the origin, then the angle ϕ'' which this tangent makes with the abscissa can be computed from the equation $\sigma_1 = \sigma_3 \tan^2 (45 + \phi''/2)$. One should always note that this angle ϕ'' is not the angle of internal friction, except in the case when the rupture line is a straight line which passes through the origin. In that case $\phi = \phi' = \phi'' =$ constant. Even though the angle ϕ'' has no physical significance in the case of a curved rupture line, it is computed for all tests because it is the simplest measure which indicates variations in the angle of internal friction. Furthermore, for practical purposes it is identical with the obliquity ϕ'. The usual deviation from it does not exceed one-quarter of a degree.

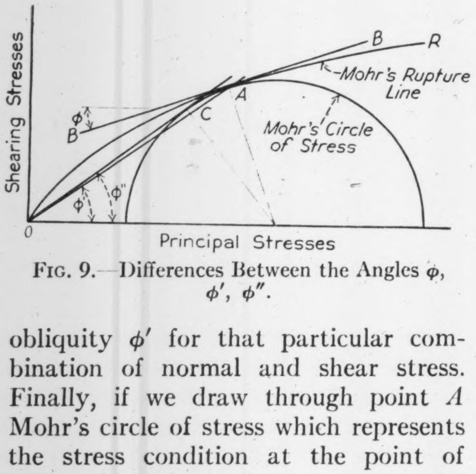


FIG. 9.—Differences Between the Angles ϕ, ϕ', ϕ''.

A plot from test results (Fig. 10) shows different shapes of the rupture line for two sands. For one (solid lines) the envelope, or rupture line, is a curve. This material is the same medium-fine sand which Figs. 7 and 8 refer to. The other material (dash lines), which has a straight line envelope, was obtained from a St. Peter sandstone of Minnesota (see Fig. 8). Both materials were packed as densely as possible for these tests. The former material, when densely packed, always failed along distinct shearing planes. The latter did not. After testing under high lateral pressure, samples of the former material could be removed from the rubber membrane and dried in an oven like a brick. After drying, it still had some cohesion and by careful handling it could be sawed open longitudinally. Then by brushing the surface with a soft brush, the shearing planes were

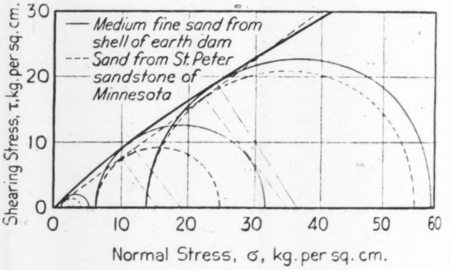
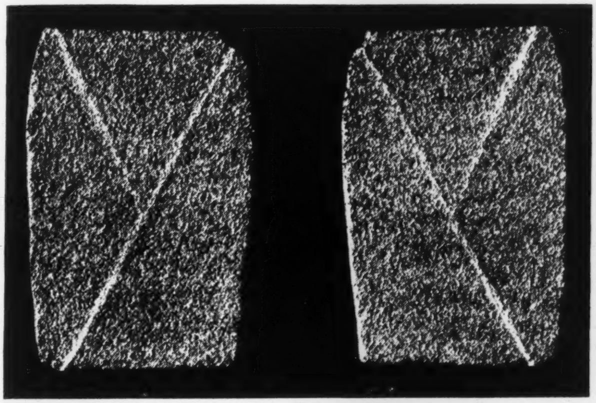
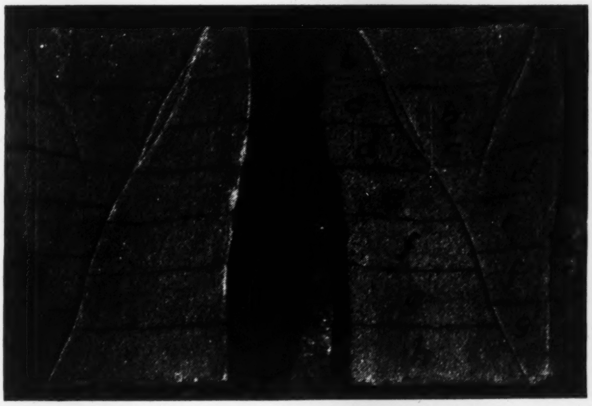


FIG. 10.—"Mohr's Circle" Diagrams for Sands in Triaxial Compression.

clearly revealed (see Fig. 11 (*a*)). Examination of such a shearing plane under a microscope showed some of the sand grains to be reduced to powder; other grains, not crushed, were held in this powder, resembling aggregate in concrete.



(*a*) Medium-fine sand from the shell of an earth dam.



(*b*) Silty fine sand from Franklin Falls, N. H.

FIG. 11.—Shearing Planes in Samples of Dense Sand.

A sample of still another sand, a very fine silty sand from Franklin Falls, N. H. (see the report previously cited for a full description[8]) (Fig. 11 (*b*)) cut open after testing to failure in a dense state, showed some interesting differences in the amount of strain in different sections of the sample. The horizontal black lines are layers of powdered charcoal. Originally these layers were equidistant. The shearing planes began at the top of the sample. The center cone, acting much like a wedge, carried a major portion of the load and was considerably compressed at its point. Then the shearing plane broke through the lower half of the sample. The probable reason for this type of progressive failure is a difference in the initial density of the upper and lower halves of the sample. Since the sample is packed in layers from bottom to top, the lower layers often become denser as a result of the extra tamping which they receive. To avoid this difficulty the upper layers must always be tamped more than the lower layers.

The unit strength of the samples was also found to be independent of the size, as shown by Fig. 12. In this figure values of the angle ϕ'' have been plotted against the initial void ratio. This material is the medium-fine sand from the shell of an earth dam, previously referred to. In a dense state there is a wide spread in the values of the angle ϕ'' depending on the magnitude of the minor principal stress. This fact is also apparent in Fig. 10 where the envelope to Mohr's circles of stress is considerably curved. But when this sand is in a loose state, there is no appreciable spread in the values of ϕ'' and the envelope is practically a straight line. It is believed that the variation in the dense state is due to a factor which is not present when the material is tested in a loose state. A dense sample fails by rupture and a crushing of grains occurs in the zones of shear (see Fig. 11). The extent to which the grains are crushed will increase with an increase of the minor principal stress. The change in the character of the material due to this crushing could, therefore, easily account for the reduction in shearing strength.

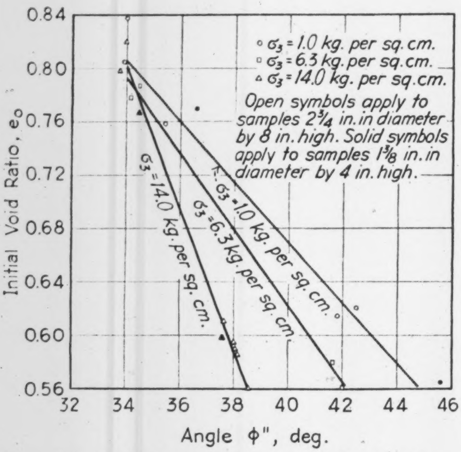


FIG. 12.—Relation Between Strength at Failure, Expressed by ϕ'', and the Initial Void Ratio.

CONCLUSIONS

On the basis of the extensive investigations which have been conducted by means of direct shear tests in the Harvard Soil Mechanics Laboratories since 1932, and the additional experience gained during the past two years through use of the triaxial compression apparatus, it is possible to formulate the following criticisms of the direct shear test:

1. The boundary conditions produce irregular distribution of the normal and shearing stresses and leave the intermediate principal stress unknown.
2. In soils which show a rapid drop in shearing resistance after the maximum value is reached, no type of grating can produce a sufficiently uniform distribution of the shearing stresses to prevent progressive failure.
3. It is practically impossible to determine in direct shear tests, with the accuracy usually required, either the strain or the volume changes during the test.

In comparison with the direct shear tests the triaxial compression tests possess the following advantages:

1. All principal stresses are known.
2. For practical purposes progressive failure is eliminated.
3. The strain and the volume changes of the test specimen can be accurately determined.
4. The size of the sample used has no apparent effect on either the intensity of volume change or the strength of the material.

5. When properly constructed the friction on the piston of this apparatus is less than 1 per cent of the load.

The following tentative conclusions concerning the shearing characteristics of cohesionless soils are drawn from many tests made with the triaxial compression apparatus on different types of sands:

1. The angle of internal friction of loose sands is practically independent of the magnitude of the normal pressure, and may vary from 28½ deg. to 35 deg.

2. Some sands in the dense state have an angle of internal friction which is independent of the normal pressure. Values of the angle of internal friction for such sands were found to range from 35 deg. to 37 deg.

Other sands in the dense state have a high angle of internal friction when the normal pressure is low, and as the normal pressure is increased the value of the angle of internal friction decreases materially. In this group of sands the maximum value of ϕ was 46 deg., the minimum value 31 deg. In the range of minor principal stresses from 0 to 14.0 kg. per sq. cm. the maximum variation found in any one of the sands tested was from 31 deg. to 43 deg.

3. The angle of internal friction for smooth-grained sands (Ottawa standard sand or St. Peter sand) is considerably lower than the angle of internal friction for rough-grained angular sands (Franklin Falls sand or quartz sand).

4. The critical void ratio is not a constant but decreases with increasing normal pressure.

Acknowledgments:

The development of the triaxial apparatus described in this paper and the investigations outlined were made possible by a cooperative agreement be tween the U. S. Engineer Office in Boston, Mass., and Professor Arthur Casagrande who served as supervisor. The author wishes to express his sincere thanks to Col. A. K. B. Lyman, District Engineer in Boston, and Capt. J. H. Stratton of the Corps of Engineers, U. S. Army, whose initiative has made this work possible.

A COMPARISON OF RESULTS OF DIRECT SHEAR AND CYLINDRICAL COMPRESSION TESTS

By Donald W. Taylor[1]

The purpose of this paper is to present a summary of recent research, carried out in the Soil Mechanics Laboratory of the Massachusetts Institute of Technology, on the shearing properties of sands, with especial emphasis on comparisons of the results of the two types of testing apparatus which are now in common use.

These two types are the direct shear machine and the cylindrical compression apparatus, the latter also known as the triaxial machine and the stabilometer. The two are so fundamentally different in principle that much value may accrue from comparisons of their results. Papers have been published[2] describing the various designs of machines of each type. The following brief descriptions are intended to outline only the basic characteristics common to all designs of each of the two types.

Direct Shear Machine:

In the direct shear type of apparatus a sample container consisting of two separate parts called the upper frame and lower frame holds the sample, half of which is within each frame. Relative motion between the two frames causes shear through the soil at the plane of separation. The shearing strength is equal to the force required to cause the relative motion. Indication of the amount of volume change which occurs during the test is obtained by a vertical extensometer dial that furnishes readings of change of thickness of sample. This was the only type of test in common use previous to a year or two ago and it probably is still the more widely used. Among its main advantages are its simplicity and speed of operation. The outstanding disadvantage is a non-uniform stress condition which leads to progressive development of failure across the sample during a test.

Cylindrical Compression Machine:

In the cylindrical compression apparatus the sample is enclosed in a rubber membrane on the outside of which fluid pressure is applied. Failure is caused by the applying of an additional axial load. The sample is saturated and a connection to a graduated glass tube is provided through the base, volume changes being indicated by the amount of water entering or leaving the sample.

The cylindrical compression machine has jumped rapidly into popularity. Its great advantage lies in the relatively uniform conditions prevailing throughout the sample, at least during the early stages of tests. This allows much better opportunity for understanding the behavior of the soil and interpreting the test data. This type of test offers great possibilities for advancement of knowledge of shearing properties of soil, as witnessed by the rapid progress it has been responsible for during the past two years.

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[1] Assistant Professor of Soil Mechanics, Massachusetts Institute of Technology, Cambridge, Mass.

[2] For direct shear apparatus see references (1) and (5); for cylindrical compression see references (2), (3), (6) and (7) in the list of references appended to this paper, p. 1070.

Scope of the Comparisons:

The question of the relative value of results from the two types of tests has been the subject of much recent discussion. One school of thought swings to an extreme and claims that the direct shear test is ready for discard. The author's beliefs on this question are the following: the value of the cylindrical test has been proven, nevertheless it has undesirable features and cannot yet be considered a perfect method; the simplicity and practical features of the direct shear test must be recognized and the amount of use made of this type of test in the future should be determined by the dependability of results which it can produce; enthusiasm for a new method is never sufficient grounds for rejecting an older, established method unless it has been definitely proven that the older method is inferior.

Research has been in progress on both types of machines in the Massachusetts Institute of Technology Soil Mechanics Laboratory during the past year. A description of the direct shear machine and a paper describing the test procedures and interpretations have already been published (**4**).[3] Research on this machine has been carried on by T. M. Leps. The design and development of the Massachusetts Institute of Technology cylindrical compression machine and the research on this apparatus is the work of H. A. Fidler and will be described in detail in a doctor's degree thesis (**7**). Figure 1 shows this machine. Both machines are motorized and operate on the strain-control scheme, that is, strains are applied at a constant rate. Each uses a proving ring unit for the measurement of the main variable force. These similarities make them especially fitted for research comparisons.

The names or designations which will be used for the soils which have been tested on both machines are as follows:

1. Ottawa standard sand,
2. Sand A,
3. Sand B, and
4. Sand BW.

Sand A is from New York state; 90 per cent by weight is finer than 0.80 mm. and 10 per cent finer than 0.18 mm.; the grains are angular; the sand is brownish gray in color and is quite dirty. Sand B is from the western part of the country, 90 per cent by weight is finer than 0.4 mm. and 10 per cent finer than 0.15 mm.; the grains are angular; sand is gray in color and is slightly dirty. Sand BW is the same as sand B but with the fine colloidal particles removed by washing.

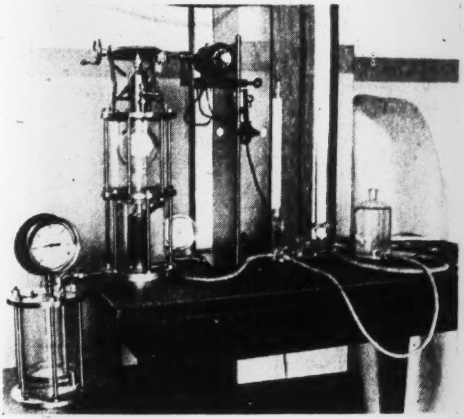

FIG. 1.—Cylindrical Compression Apparatus.

The shearing properties which will be compared are the following:

1. Maximum angle of internal friction.
2. Shape of the shearing-stress *versus* shearing-strain curve.
3. Critical void ratios.

Figure 2 shows the scheme used for plotting the results of an individual test by the direct shear machine. At a horizontal displacement of Oa_1, the upper curve reaches its maximum ratio of shearing stress to normal stress, τ/σ, represented by a_1b_1 and equal to the tangent of the maximum friction angle, ϕ_m; at this point the thickness change is c_1d_1. The ultimate point is assumed to be reached when the thickness change reaches a maximum value, c_2d_2; at this point the horizontal displacement is Oa_2 and the ratio of shearing stress to direct stress reaches its ultimate value, a_2b_2, which is equal to the tangent of the ultimate friction angle, ϕ_u.

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[3] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 1070.

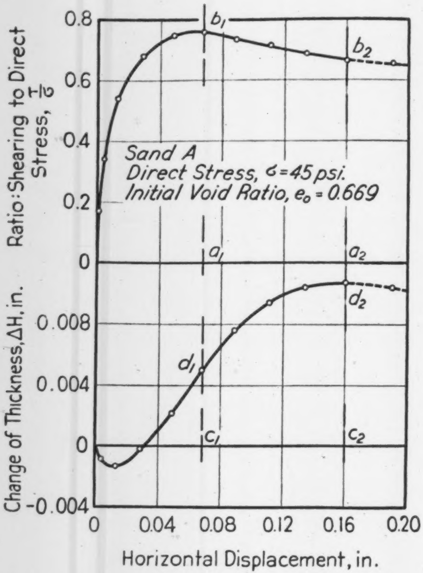


FIG. 2.—Typical Plots, Direct Shear Test.

Figure 3 presents the typical plotting scheme for a cylindrical compression test. The axial pressure, p, equals the difference between the major and minor principal stresses σ_I and σ_{III}; at an axial direct strain (ratio of change of length to initial length) of Oa, the value of p/σ_{III} reaches a maximum p_m/σ_{III} equal to ab; at this point the volume change is cd. The maximum friction angle may be computed by use of the equation

$$\sin \phi_m = \frac{\dfrac{p_m}{\sigma_{III}}}{\dfrac{p_m}{\sigma_{III}} + 2}$$

Ultimate values in this type of test tend to be somewhat erratic and are not included in the comparisons.

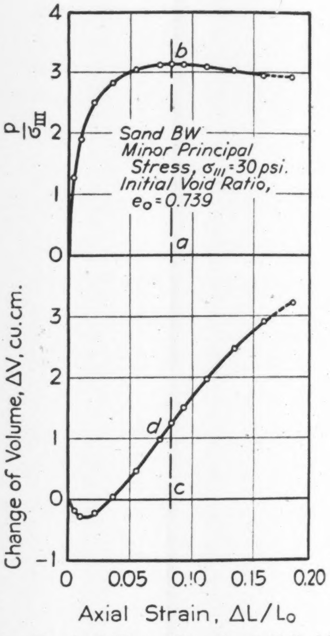


FIG. 3.—Typical Plots, Standard Cylindrical Compression Test.

Maximum Friction Angle Comparisons:

The maximum friction angle depends on the void ratio of the sample and, to a smaller degree, on the pressure. Figure 4 is a plot of results by both types of machines for sand B at minor principal stresses of 18 and 34 psi. The values by cylindrical compression tests are shown by dashed lines while those by direct shear tests are given by full lines. Points are shown for individual tests by the cylindrical compression method and it may be noted that while there is some scattering, the final curves are quite well defined. Points for individual tests by the direct shear method are less scattering and are not plotted to avoid confusion on the figure. A fairly good conception of the agreement between the two methods can be obtained from results at the loosest and densest states and such results for all four sands are compiled in Table I. It is seen that for dense Ottawa sand at low pressures the disagreement is greatest and equals about 4 deg. Other differences do not exceed about 2 deg. and on the average are equal to about 1 deg. The friction angles tend to be larger by the direct shear method, especially for the dense state.

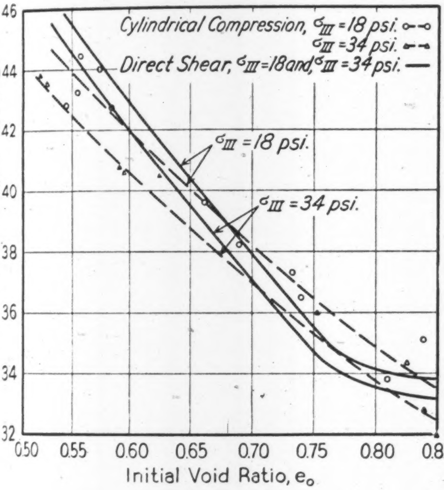


FIG. 4.—Typical Friction Angle Comparison, Sand B.

It has been known for a number of years that the friction angle as determined by direct shear tests varies with the size of sample and conditions of testing. Comparisons of results from different makes of direct shear machines have shown variations fully as large as those appearing in this table.

From Table I the conclusion may be drawn that the agreement in friction angles by the two methods is not as close in all cases as would be desirable from the research point of view, but from the practical viewpoint the agreement is reasonable.

The ultimate friction angle as determined by the direct shear machine is a constant and equals 26.7 deg. for Ottawa sand, while for sands A, B, and BW it equals 33 deg.

Stress-Strain Curve Comparisons:

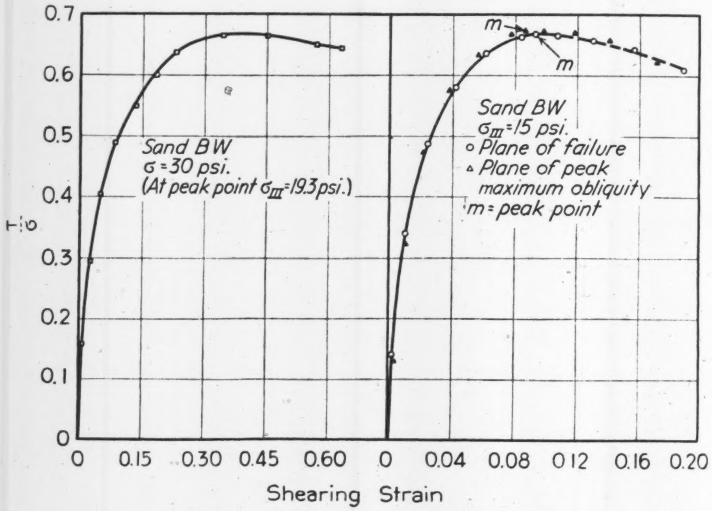
A proposed method for determining the approximate plot of shearing stress against shearing strain from direct shear test data was described in a previous report (4). Fig. 5(*a*) is a plot based on this method. In the direct shear test the stress conditions on planes other than the plane of failure are statically indeterminate and there is no way that this plot can be transformed into one for comparison with results of cylindrical compression tests. However, in the cylindrical test the stresses and strains are known for all orientations of planes

TABLE I.—MAXIMUM FRICTION ANGLE COMPARISONS.

Soil	Stress, σ_{III}, psi.	Initial Void Ratio, e_o	Maximum Friction Angle, ϕ_m, deg.		
			By Direct Test	By Cylindrical Test	Difference
Ottawa sand....	20	0.65	28.5	26.7	1.8
		0.55	34.1	30.3	3.8
	60	0.65	27.2	26.4	0.8
		0.55	31.1	30.3	0.8
Sand A..........	15	0.75	33.9	35.1	−1.2
		0.60	41.7	40.5	1.2
	30	0.75	33.5	33.8	−0.3
		0.60	39.9	39.3	0.6
Sand B..........	18	0.85	33.8	33.8	0.0
		0.60	42.8	41.9	0.9
	34	0.85	33.2	31.6	1.6
		0.60	42.0	40.7	1.3
Sand BW.......	30	0.85	33.8	34.0	−0.2
		0.65	44.4	41.8	2.6
	60	0.85	32.7	32.2	0.5
		0.65	42.6	39.6	3.0

and the data of any such test may be transformed into a plot with coordinates as in Fig. 5(*a*). The plot which is desired must show the relationship between the τ/σ ratio on the plane on which failure ultimately occurs and the shearing strain for this same plane.

A description which holds for shearing strain as this term is understood in the direct shear test and therefore one which will hold for the transformed plot of the cylindrical test is as follows: the shearing strain for any plane is the cotangent of the angle between the given plane and the plane which at the outset of the test was normal to this plane. For example in Fig. 10, *Oa* and *Of* are the initial positions of two 90-deg. planes, that is, $\theta_0' + \theta_0 = 90$ deg.; after distortion the positions become *Oc* and *Od*; at this distortion the tangent of the angular difference, or $\cot(\theta + \theta')$ is the shearing strain for these planes.



(*a*) Direct shear method. (*b*) Cylindrical compression method.

FIG. 5.—Typical Comparison of Curves of Shearing Stress Against Shearing Strain.

Data on the unit changes of length and of volume are the only quantities needed for computing shearing strains on any plane in the cylindrical sample. The method of computation is given in the Appendix.[4]

The location of the plane on which failure occurs in a cylindrical test is not as definitely known as has sometimes been intimated. It is usually assumed that failure will occur on the plane of maximum obliquity, that is, on a plane located at an angle of 45 deg. + $\frac{1}{2}\phi$ from the major principal plane. The sample represented by Fig. 5 has a friction angle of 34 deg.; thus according to theory the failure plane should have been at an angle of 62 deg. to the horizontal. However the actual angle was 58 deg. The fact that failure does not occur on the plane of maximum obliquity is the rule and not the exception, and it has been found that the failure plane frequently differs from the plane of maximum obliquity by more than the 4 deg. of this illustration.

This point is mainly one of academic interest, however, as is seen in Fig. 5(*b*), where τ/σ is plotted against shearing strain for both of the planes under discussion. In this figure the maximum obliquity at the peak point of the curve is 33.9 deg.; the obliquity on the plane of failure at the same instant is 33.6 deg. A difference in obliquity of 0.3 deg. occurs for planes which are 4 deg. apart; in other words, the obliquity is practically the same on the two planes. The curve appearing in Fig. 5(*b*) with points shown by circles, is for the failure plane; the points for the other plane are shown by triangles and differ from the curve by amounts so small that drawing of a second curve has not been attempted.

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[4] See p. 1069.

The reason for the occurrence of failure on a plane where the obliquity is slightly below the maximum value is believed to be the following. Dense sands always have a larger friction angle than loose sands which is attributed to a greater interlocking of particles, this interlocking and the friction angle being decreased by increase of shearing strain (see Fig. 2, curve b_1b_2). Since there is no reason that interlocking must be the same for all orientations of planes and since the shearing strain is greater on the failure plane than on the plane of maximum obliquity (0.093 as compared to 0.086, as shown in Fig. 5(*b*)), it follows that the friction angle on the failure plane is slightly less than it is on the plane of maximum obliquity.

The shearing strains in Fig. 5(*b*) are true values according to the description which has been given above for shearing strain. Those in Fig. 5(*a*) are values obtained by dividing the horizontal displacement by the "effective thickness," this thickness being determined by the scheme described in the previous report (4). A pronounced disagreement is seen and it now becomes evident that the proposed scheme of determining effective thickness must be abandoned. It may be noted, however, that this is the only proposed item in this previous report which fails to give reasonable results. By working backwards, dividing strains as shown in Fig. 5(*b*) by the horizontal displacements occurring in the direct shear test, an effective thickness of sample is indicated which would be about twice as large as the actual thickness of the direct shear sample. Two possible explanations of this apparent paradox can be mentioned. The resistance to shear in the direct shear test may involve, because of the progressive failure, more rolling friction and less sliding friction than occur in uniform strain, thus leading to larger apparent shearing strains. Again, since the direct shear sample distorts essentially in plane strain, its distortions would normally be larger than would occur in a case where strains are not limited to two dimensions.

The different abscissa scales of Fig. 5 have been chosen to furnish the best opportunity for comparison of the general forms of the curves. It is of interest to note the remarkably close resemblance between the shapes of the curves by the two methods. It is possible that future studies may be able to attach some significance to this similarity.

Critical Void Ratios Comparisons:

One of the most important developments in soil mechanics during the past few years is the concept of critical void ratios. While several types of critical void ratios have been proposed, a general explanation can be given which holds for all types.

Loose sands tend to decrease in volume during shear while dense sands tend to expand. In saturated soils, a decrease of volume requires escape of water and in large masses of soil, this escape may require considerable time. As a result, the water may be trapped and subjected to stress. In sand, the strength depends directly on the intergranular pressure and transfer of pressure into the pore water changes the intergranular stress correspondingly. Thus, in loose sands, transfer of pressure to the water makes the mass less rigid and in extreme cases it may even be thrown into a "quick" or "liquefied" condition. Conversely, if the sand is dense, the tendency is to draw in water during shear and any delay in expansion will throw negative stress or tension into the water, the intergranular stress increasing accordingly, giving the sand mass an additional strength of a temporary nature. Somewhere between the loose and dense extremes is an intermediate density where tendency toward volume changes are in balance and at which the dependable strength of the mass is alike whether dry or saturated. This density is the critical density and its void ratio is the critical void ratio.

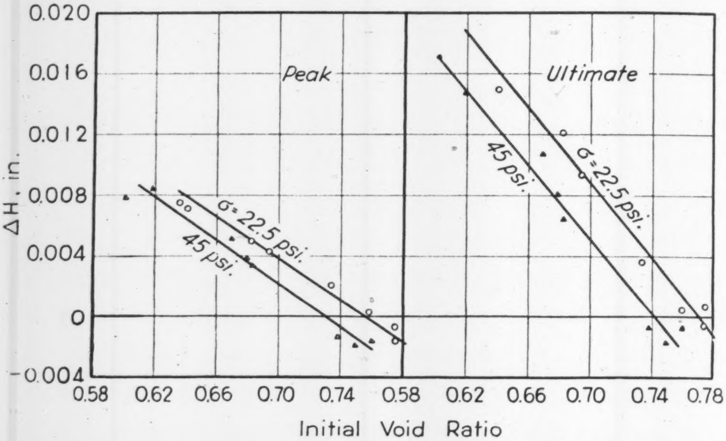

FIG. 6.—Typical Plots for Determination of Peak Critical Void Ratio and Ultimate Void Ratio by Direct Shear Tests, Sand A.

The methods for determining critical void ratios will be outlined briefly. A series of tests starting at various initial void ratios is required for each normal load that is investigated. Figure 2 shows the data available from a single test in direct shear and from such data a plot may be drawn for the series to show the relationship between initial void ratio and change of thickness, c_2d_2. The initial void ratio at which this plot shows a change of thickness equal to zero is the ultimate void ratio (also called the upper critical void ratio) for the normal load used. Similarly, on a plot of initial void ratio against volume change c_1d_1, the initial void ratio at which the change of thickness is equal to zero is the peak (or lower) critical void

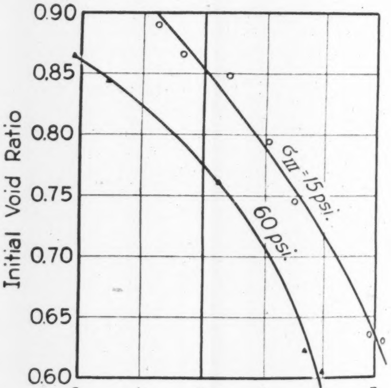

FIG. 7.—Typical Plot for Determination of Peak Critical Void Ratio by Standard Cylindrical Compression Tests, Sand BW.

ratio. Plots of these types for sand A at normal loads of 22.5 and 45 psi. are shown in Fig. 6.

For the cylindrical compression method a similar procedure for determining the peak critical void ratio has been outlined by A. Casagrande (3) and consists of plotting the volume change (*cd* of Fig. 3) against initial void ratio, for a series of tests at a given minor principal stress. Figure 7 shows plots of this type for sand B at minor principal stresses of 15 and 60 psi. It is seen that well-defined curved lines are obtained.

The peak critical void ratio has been determined for each of the four soils of this investigation by both types of apparatus and the results are presented in Table II. Ultimate void ratios have been determined by direct shear tests and these values are also given. The final column of this table refers to a new concept of critical void ratio which will be described later.

TABLE II.—CRITICAL VOID RATIO COMPARISONS.

Soil	Stress, σ_{III}, psi.	Peak Critical Void Ratio			Ultimate Void Ratio	Equal Strength Void Ratio
		Direct Tests	Cylindrical Tests	Difference	Direct Tests	Cylindrical Tests
Ottawa sand	20	0.66	0.65	0.01	0.68	....
	40	0.65	0.645	0.005	0.67	....
	60	0.645	0.64	0.005	0.66	....
Sand A	15	0.75	0.68	0.07	0.77	....
	30	0.73	0.64	0.09	0.74	....
Sand B	18	0.85	0.81	0.04	0.86	....
	34	0.81	0.76	0.05	0.82	....
Sand BW	30	0.86	0.815	0.045	0.88	0.85
	60	0.84	0.78	0.06	0.87	....

Study of the peak critical void ratios in Table II shows immediately that the values obtained by the two types of apparatus are not the same. The results by the direct shear method are consistently larger than those by the cylindrical method. The difference is small for Ottawa sand while for the other three sands it varies from 0.04 to 0.09, averaging about 0.06.

Because of the approximately uniform stress condition in the cylindrical compression apparatus, it is reasonable to believe the values by this method are the more accurate. However, one qualification to this statement should be pointed out. In the cylindrical test the volume change in the early stages of the test is probably distributed quite uniformly throughout the sample. Shortly after passing the peak point (point *b* of Fig. 3), a definite failure plane becomes visible, and from this point on all strains occur in a relatively small failure zone. Practically all of the volume change must occur within this small zone once it has developed. The method for determining the peak critical density involves the assumption that, up to the peak point, volume changes are uniform throughout the sample. Even though there is no sign of a failure plane when the peak point is reached, it is possible that such a plane is already incipient and the neighborhood of this plane is already taking more than its share of volume change. Such a condition would mean that the true critical void ratio is higher than the value given by the method now in use.

The question of the degree of dependability which can be attached to peak critical void ratio values determined by the direct shear method, is for practical reasons an important one. Ottawa sand cannot be called a typical sand and if only the results from the other three sands are considered it would appear that the difference between the results by the two methods is reasonably constant. By subtracting 0.06 from figures obtained by the direct shear method, values approximating those by the cylindrical compression method are obtained. This scheme looks sufficiently promising to warrant further investigation, but no definite conclusions should be drawn until comparative values are available for more than four soils.

A part of this difference in results is probably caused by variations of σ_{III} in direct shear tests, whereas this variation does not occur in cylindrical tests. However a determination of the importance of this factor can be obtained only by further research.

The Equal Strength Void Ratio:

As the peak of the curve (point b_1, Fig. 2, or point b, Fig. 3) is approached, the values of thickness change ΔH, and volume change ΔV are increasing so rapidly that determinations of their magnitudes at the peak are subject to large inaccuracies. This is a very undesirable feature and might even be taken as an indication that there should be some more fundamental scheme of describing the critical condition than the one used. Actually, knowledge of the peak critical density is itself of indirect value only; the information really wanted relates to the amount of shearing strength available if a sand, looser than the critical density, is sheared with volume changes prohibited.

The direct way to obtain such information would be to conduct tests wherein the sample volume is maintained constant. However, such a condition cannot be obtained by merely closing off the sample to all escape of water, as during the test neutral pressures would develop and because of the air which is present in the pore water of the sample, appreciable compression would occur. Generally the pore water in nature also contains small amounts of gaseous matter, but a laboratory test with drainage prevented would be representative of a case without drainage in nature only if the percentages of air voids were alike in the test and in nature. Since numerous difficulties would be met in attempts to determine amounts of air voids, it is fortunate that it is on the side of safety to assume that the pore fluid is incompressible and therefore that in tests without drainage there are no variations in the volume of the sample. A type of test which will now be described and which will be called the "constant volume test," maintains a strictly constant volume throughout the test and may be run in the cylindrical compression apparatus without any appurtenances other than those needed for the standard test.

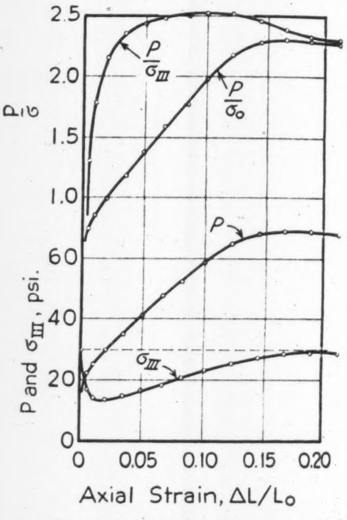

FIG. 8.—Typical Plots, Constant Volume Cylindrical Compression Tests, Sand BW, $e_0 = 0.861$, $\sigma_0 = 30$ psi.

The constant volume test is run with the pore water at atmospheric pressure. Instead of observing the volume changes by readings of the water level in the tube appearing just to the right of the motor in Fig. 1, the valves controlling the lateral pressure are manipulated continuously to maintain a constant water level. Any tendency toward decrease in volume may be counteracted by a reduction in σ_{III} and *vice-versa*. The essential difference from the standard test is that readings of the minor principal stress σ_{III} and the principal stress difference, p, as taken, whereas in the standard test σ_{III} is constant and readings of the principal stress difference and volume change are recorded. The essential data of a typical constant volume test are presented in graphical form by the two lower curves of Fig. 8.

As a means of interpreting the relationship between the constant volume test and a constant volume case in nature, let it be imagined that alongside of the constant volume test, a second test with identical initial conditions is set up wherein the voids of the sample are filled with an incompressible fluid and wherein constant volume is maintained by sealing the sample, thus preventing the escape of any pore water. When the constant volume test and this assumed test have undergone the same compression, they will both show the same lateral bulging. The two tests are then under like strains and it follows that they must be under like intergranular pressures. The only difference between the two is that in the assumed test the pore fluid is under pressure while in the actual test it is not. Since neutral pressures play no part in developing strength, the results of the two tests, as commonly presented in the form of plots of intergranular stress against strain, will be the same.

The above considerations apply regardless of what the total (effective plus neutral) applied pressures may be during the assumed test. For any given axial compression, the amount of effective minor principal stress is known from the data of the actual constant volume test. The greater the applied total minor principal stress in the assumed test, the greater the neutral pressure will be, while if the total applied lateral pressure is less than the actual test shows, the neutral pressure must be negative which means the pore water must be in tension. However, the constant volume case in nature for which information is desired herein is that which is under the same total loading as the standard laboratory test, that is, at constant total minor principal stress. Thus, the constant volume case in nature for any given amount of strain would have the effective minor principal stresses indicated by the constant volume test while its neutral pressure would be the difference between this effective value and the constant total minor principal stress, the constant total value being equal to the initial effective value which will be designated by σ_0.

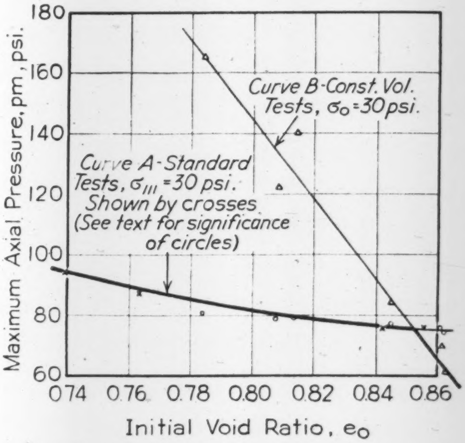

FIG. 9.—Typical Plot for Determination of Equal Strength Void Ratio.

The measure of shearing strength commonly used is the friction angle. However, the maximum value of $\frac{p}{\sigma_{III}}$ as obtained from Fig. 3, could be used as the measure of strength, or since σ_{III} is a constant, p_m, the maximum value of p, may be used to express the shearing strength. In a series of standard tests at a given constant value of σ_{III}, each test furnishes one point on a plot of p_m against initial void ratio. Curve A

of Fig. 9 is a plot of this type, individual tests being represented by crosses. Curve *B* of this figure is obtained from a series of tests of the constant volume type starting with the same initial conditions as the standard series, that is, with the initial stress σ_0 of the constant volume tests equal to the constant value σ_{III} of the standard series.

The $\frac{p}{\sigma_{III}}$ curve for the constant volume test of Fig. 8 is seen to resemble the same curve for the standard test of Fig. 3. If the friction angle were independent of the stress σ_{III}, then for any given initial void ratio there should be like maximum values of $\frac{p}{\sigma_{III}}$ by these two types of tests. The maximum values by standard tests, multiplied by the constant value of σ_{III}, furnish the points shown by crosses in curve *A* of Fig. 9; similar maximum $\frac{p}{\sigma_{III}}$ values by constant volume tests, multiplied by the stress σ_0, give the points along curve *A* shown by circles. The agreement between the two types of points shows that the friction angle is, in this instance, essentially independent of stress σ_{III}; when such agreement occurs, curve *A* as well as curve *B* may be obtained from results of constant volume tests alone.

The intersection of the two curves of Fig. 9 furnishes a new type of critical void ratio which will now be described. At the initial void ratio given by this point of intersection, tests of either type show like compressive strengths, p_m. Since the constant volume test is representative of the constant volume case in nature wherein the total applied σ_{III} (effective plus neutral) is constant, it is seen that both this case and the standard test have like applied loads and like compressive strengths. It may therefore be concluded that they have like strengths in shear. It should be noted, however, (see the $\frac{p}{\sigma_0}$curve of Fig. 8) that the strains required to develop the like strengths are not the same for the two. Figure 9 thus furnishes the density at which equal strength is obtained whether volume changes occur with perfect freedom or are completely prevented. If the purpose of a critical void ratio is to indicate the density below which there is loss of strength because of a "quick" condition, then it is believed there is no void ratio which is more "critical" than this value. It will be given the name of "equal strength void ratio."

For general use the lower, or safer strength curve of Fig. 9 should be used; therefore the lower branches of the curves are shown by heavy lines. This composite heavy line may be referred to as describing the dependable strength, so long as there is no possibility of occurrence of dangerous vibrations.

It has been suggested that there is a possibility that volume changes are not uniform throughout the sample in the standard cylindrical compression test; a similar possibility exists in the test at constant volume, as a central failure zone which is expanding may be balanced by small compressions in the remainder of the sample. Further investigation of this possible sourse of inaccuracy is needed.

In Fig. 8 it is seen that the strain at the peak point of the p/σ_0 curve is large, more of the order of the strain for an ultimate point than that for a standard peak point (see Fig. 3). This indicates that the value of "equal strength void ratio" should fall nearer that of the ultimate than the peak critical void ratio. This is roughly borne out by the single numerical comparison which is available and appears in the last column of Table II. Its value in this instance exceeds the peak critical value by the cylindrical method by an amount slightly greater than that by which ultimate values exceed peak critical values in the direct shear method.

CONCLUSIONS

It could hardly be expected that results by two methods so widely different in nature as are the direct shear and cylindrical compression methods would show exact agreement. The comparisons presented herein in some instances show appreciable disagreements but it is believed that on the whole they are encouraging.

The average difference in maximum friction angle by the two methods is 1 or 2 deg. Although comparisons of shearing strains are not in agreement, the shapes of shearing stress versus shearing-strain plots show remarkable correspondence. Peak critical void ratios are consistently larger by the direct shear method, but by an amount which is indicated as being roughly constant.

The cylindrical compression machine is recognized as the more valuable for fundamental research. A limitation of this apparatus is that ultimate properties cannot be obtained satisfactorily on it. The direct shear apparatus is more rapid and simpler and it is believed that in testing work of a routine nature, especially after more comparisons are available to serve as a calibration, this apparatus will furnish the majority of the shearing properties of sand with satisfactory accuracy.

Use of a new critical void ratio called the "equal strength void ratio" is suggested. Since determination of its value requires constant volume tests, it cannot be obtained directly by direct shear testing but it is believed it is closely related to the ultimate critical void ratio.

APPENDIX

DETERMINATION OF SHEARING STRAINS

The plane for which shearing strains will be desired will usually be the plane on which failure occurs, but the strains may be obtained for any plane by the method given herein.

At the peak point (point *b*, Fig. 3), the angle between the arbitrarily chosen plane for which shearing strains are to be computed and the reference plane will be designated by θ. The reference plane for all angles described herein will be the horizontal plane which is the major principal plane. Let θ_0 be the angle for this same arbitrarily chosen plane (the plane through the same soil particles) at the beginning of the test and θ_1 its angle at any given intermediate stage during the test. The plane which is normal to the above-mentioned plane at the outset of the test will be at the angle of $\theta'_0 = 90 - \theta_0$. To designate the angles for this second plane at the intermediate and peak stages, respectively,

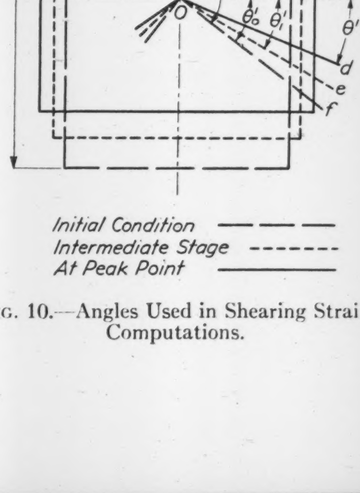

FIG. 10.—Angles Used in Shearing Strain Computations.

θ'_1 and θ' will be used. These angles are shown in Fig. 10. If diameter is designated by D, effective length by L and volume by V and if zero subscripts are used to signify initial values and the subscript one for values at any given intermediate stages:

$$\frac{\pi}{4} D_0^2 L_0 = V_0$$

$$\frac{\pi}{4} (D_0 + \Delta D)^2 (L_0 + \Delta L) = (V_0 + \Delta V)$$

or

$$(1 + \Delta D/D_0)^2 (1 + \Delta L/L_0) = (1 + \Delta V/V_0)$$

$$\text{whence } (1 + \Delta D/D_0) = \sqrt{\frac{1 + \Delta V/V_0}{1 + \Delta L/L_0}}$$

The relationship between initial and final angles will be

$$\tan\theta = \frac{1 + \Delta L/L_0}{1 + \Delta D/D_0} \tan\theta_0$$

$$= \sqrt{\frac{(1 + \Delta L/L_0)^3}{(1 + \Delta V/V_0)}} \tan\theta_0$$

$$\text{Letting} \quad \frac{(1 + \Delta L/L_0)^3}{1 + \Delta V/V_0} = K$$

$$\text{gives} \quad \tan\theta = \sqrt{K} \tan\theta_0$$

$$\text{or} \quad \cot\theta_0 = \sqrt{K} \cot\theta$$

$$\text{Also } \tan\theta' = \sqrt{K} \tan\theta'_0 = \sqrt{K} \cot\theta_0$$

$$\text{and} \quad \tan\theta' = K \cot\theta$$

The angle between the two planes is initially $\theta_0 + \theta'_0$ which equals 90 deg. At the intermediate stage it becomes $\theta_1 + \theta'_1$ and finally at the peak it equals $\theta + \theta'$. Shearing strains are herein described as the cotangents of these angles. The shearing strain ϵ is initially equal to cotan 90 deg. or zero and at the peak point it becomes:

$$\begin{aligned} \epsilon &= \cot(\theta + \theta') \\ &= \cot(\theta + \tan^{-1}[K \cot\theta]) \end{aligned}$$

To express the shearing strain at any intermediate point

$$\text{let } K_1 = \frac{(1 + \Delta L_1/L_0)^3}{1 + \Delta V_1/V_0}$$

and, similar to the previous derivation,

$$\begin{aligned} \epsilon &= \cot(\theta_1 + \theta'_1) \\ &= \cot(\theta_1 + \arctan[K_1 \cot\theta_1]) \end{aligned}$$

$$\text{wherein } \theta \sim = \arctan\left[\sqrt{\frac{K_1}{K}} \tan\theta\right]$$

whence the following general formula for shearing strain is obtained:

$$\epsilon_1 = \cot\left(\tan^{-1}\left[\sqrt{\frac{K_1}{K}} \tan\theta\right] + \tan^{-1}\left[\sqrt{K_1 K} \cot\theta\right]\right)$$

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SOME INVESTIGATIONS OF THE SHEARING RESISTANCE OF COHESIONLESS AND COHESIVE MATERIALS

By D. M. Burmister[1]

Shearing phenomena in cohesionless and cohesive soils are in certain respects identical, but in other important respects are fundamentally different. Certain similarities and differences in behavior, together with the influence of certain aspects of testing procedure are discussed in relation to the consistency of results, using the direct-shear strain-control type of shearing apparatus. Investigations were made on standard Ottawa sand, 20 to 30 mesh and on a Detroit clay, furnished by W. S. Housel, University of Michigan, as a part of the research project of Subcommittee VII of the Society's Committee D-18 on Soils for Engineering Purposes, to determine the consistency of results obtained from different laboratories using different types of shearing apparatus and different testing procedures.

The tests on Ottawa sand were made by Paul Hartman, graduate student, and the tests on the Detroit clay were made by H. C. Sperry, graduate research assistant in soil mechanics, Department of Civil Engineering, Columbia University.

Apparatus:

The shearing apparatus is illustrated in Fig. 1. The shear box, $2\frac{1}{2}$ by $3\frac{1}{2}$ in., is of the direct-shear Harvard type, equipped with a metal tooth grid for the tests on Ottawa sand, and with coarse grade porous stones for the tests on the Detroit clay. The normal pressure is applied on the shearing bench by means of a simple counterbalanced beam system and dead weights. The horizontal shearing load is applied by a motor-operated gear-reduction device through a loading bar, which permits either of two shear tests to be made independently of the other. The horizontal shearing load is measured by means of a calibrated loading ring, fitted with an Ames dial to indicate the deflection of the ring under load. The capacity of the loading ring is about 700 lb. at two revolutions of the 1/10,000 Ames dial. The horizontal shearing deformation and the vertical expansion or compression of the soil during shearing were measured by the Ames dial as indicated. The shear loading device is of the "constant strain" or strain-control type, the rate of shearing being controlled by means of a rheostat and a time-delay relay.

Shear Tests on Standard Ottawa Sand:

The tests on Ottawa sand representing as one extreme a cohesionless material were part of a study to determine the shearing characteristics of the material as influenced by such physical factors as initial voids ratio or density and initial thickness of the sample. In each case a known weight of the dried material was placed in the shear box in layers, brought to the desired condition of density, and carefully leveled off with a special adjustable screed. The initial thickness of the layer was carefully determined by means of a calibrated straddle gage and an Ames dial after placing the upper grid in position. From these measurements, after correcting the volume of the sand for the teeth of the grid, the voids ratio was computed.

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[1] Assistant Professor of Civil Engineering, Columbia University, New York City.

Two of the series of tests contemplated were completed, for two limiting density states—about the loosest possible condition with an average voids ratio of about 0.66, and a very dense condition with an average voids ratio of about 0.50. Particular care was taken to obtain as uniform a density condition for these two series as possible.

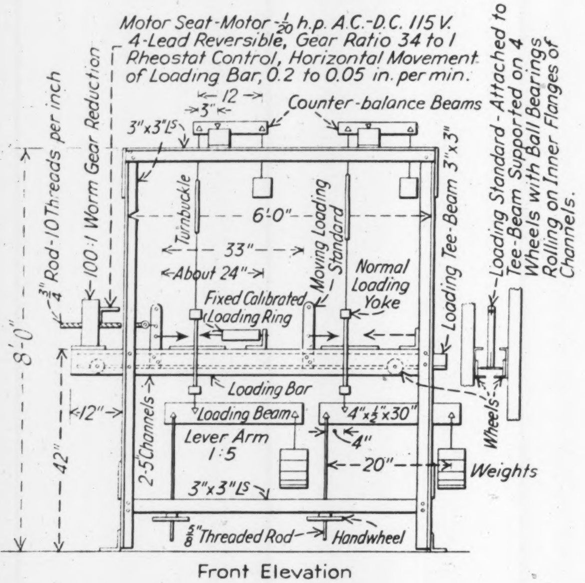

Motor Seat-Motor-$\frac{1}{20}$ h.p. A.C.-D.C. 115 V.
4-Lead Reversible, Gear Ratio 34 to 1
Rheostat Control, Horizontal Movement of Loading Bar, 0.2 to 0.05 in. per min.
12
3"
Counter-balance Beams
3"x3"L^s
$\frac{3}{4}$" Rod-10 Threads per inch
100:1 Worm Gear Reduction
Loading Standard - Attached to Tee-Beam Supported on 4 Wheels with Ball Bearings Rolling on Inner Flanges of Channels.
Turnbuckle
6'-0"
Moving Loading Standard
33"
About 24"
Normal Loading Yoke
Fixed Calibrated Loading Ring
Loading Tee-Beam 3"x3"
8'-0"
Loading Bar
12"
2-5" Channels
Loading Beam
4"x$\frac{1}{2}$"x30"
Wheels
Lever Arm 1:5
4"
20"
Weights
42"
3"x3"Ls
$\frac{5}{8}$" Threaded Rod
Handwheel
Front Elevation

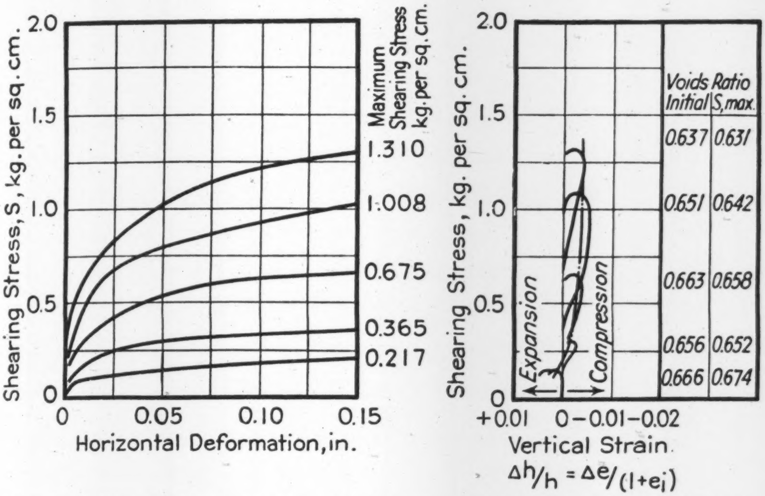
FIG. 1.—Shear Loading Apparatus.

Upper half of shear box fixed and attached to calibrated loading ring to measure horizontal shearing load. Lower half of shear box movable and attached to loading standard.

The loose state was obtained by permitting the sand to flow gently out of a small funnel, spreading the sand in layers by moving the funnel back and forth in a regular pattern to fill the shear box. The dense state was obtained by applying vibrating blows to the upper grid until no further volume decrease could be detected by the straddle gage. The initial voids ratio in these tests refers to the voids, either in the loose or dense condition, respectively, under the desired normal loading. This initial voids ratio was computed after observing the change in the vertical dial reading upon application of the desired normal load.

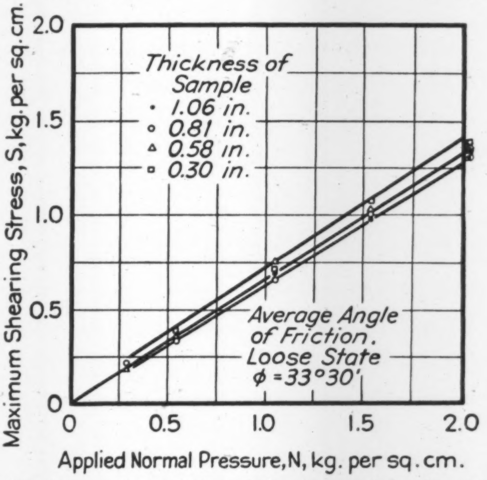
Because it was thought that the thickness of the test sample might have an appreciable influence on the results of the direct-shear tests on granular materials, a series of tests was made on samples having initial thicknesses of approximately 0.32, 0.56, 0.80, and 1.05 in.

The results of these tests are summarized in Figs. 2, 3, and 4. These curves bring out characteristic differences in the shearing behavior of the material in the loose and dense states. The first characteristic feature has to do with the stress-shearing deformation relations. In the loose state, Fig. 2(*a*), the shearing stress increases gradually and continuously to a maximum which is reached at a rather large horizontal deformation of about 0.20 in. (not shown on the curves) for a sample 0.80 in. thick. On the other hand, in the dense state, Fig. 3(*a*), the shearing stress increases rapidly to a much higher maximum than for the loose state, which occurs at quite a small horizontal deformation, comparatively of about 0.025 in. Thereafter with increasing horizontal deformation the stress drops off in a characteristic fashion quite rapidly to a value about two-thirds to three-fourths of the maximum value. This is of the nature of a rupture failure and is characteristic of shearing failure in the dense



(*a*) Stress-shearing deformation relations for different applied normal pressures.

(*b*) Stress-volume change relations during shearing.

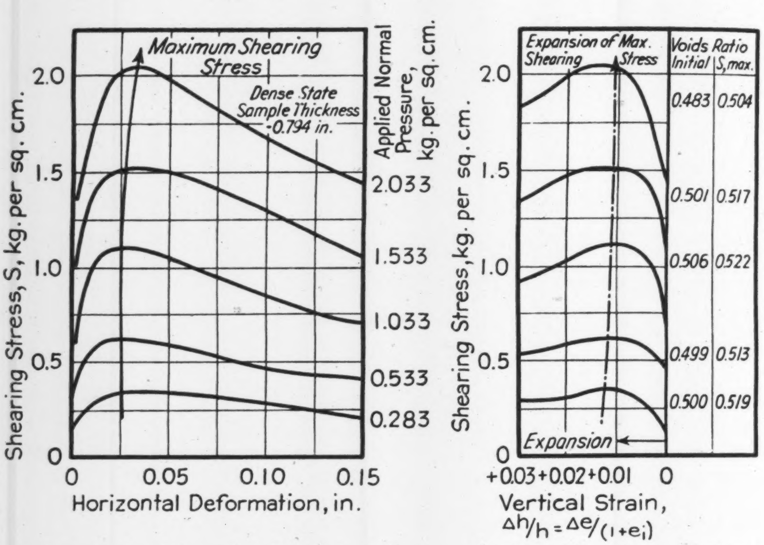


(*c*) Relation between the applied normal pressure and shearing strength.

FIG. 2.—Shearing Characteristics of Standard Ottawa Sand, 20–30 mesh.

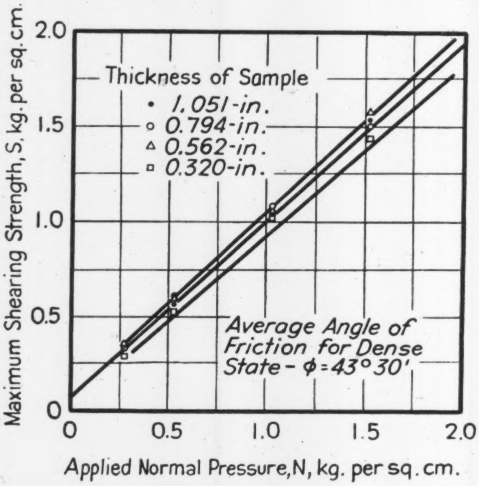
Shear tests made on sand in the loose state. Harvard-type shear box 2½ by 3½ in. Constant rate of strain type of shearing loading, average rate, 0.005 in. per min.

state. In the loose state the failure is more of the nature of a plastic flow.



(*a*) Stress-shearing deformation relations for different applied normal pressures.

(*b*) Stress-volume change relations during shearing.



(*c*) Relation between the applied normal pressure and shearing strength.

FIG. 3.—Shearing Characteristics of Standard Ottawa Sand, 20–30 mesh.

Shear tests made on sand in the dense state. Harvard-type shear box $2\frac{1}{4}$ by $3\frac{1}{2}$ in. Constant rate of strain type of shearing loading, average rate 0.05 in. per min.

While the maximum shearing strength is greatly affected by the initial voids ratio, it has been shown by Taylor and Leps (**1**)[2] that the ultimate shearing strength is very little affected and has about a constant value for all density states. This is clearly shown in Fig. 4(*a*) for the loose and dense states by plotting the ratio S/N (shearing stress to normal stress) against horizontal deformation as suggested by Taylor.

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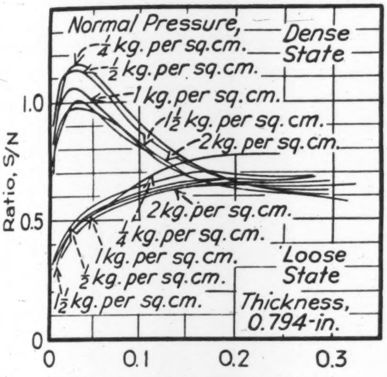
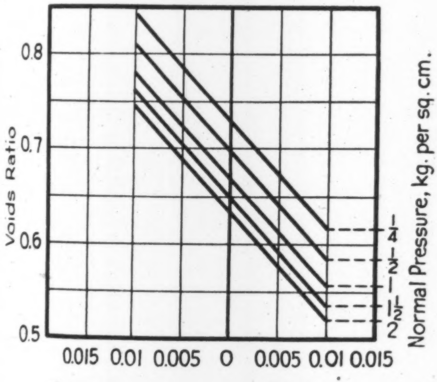
[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 1082.

The second characteristic feature is the volume change which always accompanies shearing action in soils. This is shown in Figs. 2(*b*) and 3(*b*), for the loose and dense states, respectively.



(*a*) *S/N* curves.



(*b*) Approximate volume change relations during shearing.

FIG. 4.—Shearing Characteristics of Standard Ottawa Sand, 20–30 mesh.

In the loose state, except under the smallest normal pressure, the material tends to decrease in volume or compress, almost from the start of the test. The reason for this phenomenon in the loose state is obvious from the mechanics of the shearing action. The mass of grains in a loose structure tends, as a result of shearing deformation with accompanying relative displacements of grains, to assume a more dense state. But invariably after the ultimate shearing strength is reached, a certain amount of expansion takes place. A point is reached where continuous shearing deformation occurs at constant maximum shearing stress and at constant volume. This is the *critical density* as first defined by Casagrande (2, 3), which is the equivalent plastic state for a granular cohesionless material. It is to be noted that there is a tendency for the magnitude of the volume decrease or compression during shear to be larger with increase in normal pressure as indicated by the trend in Fig. 4(*a*).

In the dense state, although there may be a slight compression during the first part of the shearing action, the material exhibits a marked and rapid volume increase or expansion near the maximum shear stress point. Such expansion is required in order to bring the material to the equivalent plastic state and to permit continuous shearing at constant stress and constant volume. For dense materials it is to be noted that the volume expansion at the maximum shear stress tends to be smaller with increase in the normal pressure as indicated in the trend of Fig. 3(*b*).

The third characteristic feature is the effect of the initial density upon the value of the angle of friction, ϕ. The failure of masses of loose grains such as soils in shear depends on the resistance to displacement of the grains, that is, upon the internal friction that can be developed. In order to determine the angle of friction it is necessary to establish the relation between the applied normal pressure and the shearing strength, which is Coulomb's simple equation for cohesionless materials:

$$S = N \tan \phi \ldots\ldots\ldots (1)$$

where:

S = the maximum shearing strength,
N = the pressure applied normal to the shearing plane, and
ϕ = the angle of friction.

This linear relation is shown in Figs. 2(*c*) and 3(*c*) for the approximate limiting loose and dense states for Ottawa sand. The slope of the mean line through the points is tan ϕ and the average value of the angle of friction ϕ for the loose state is 33 deg., 30 min., and for the dense state is 43 deg., 30 min., which represents a very considerable difference in the value of ϕ with extremes of density. A comparison with the value obtained for the ultimate stress found from Fig. 4(*a*) shows that the loose state and the ultimate shear stress conditions have almost identical angles of friction with an average of 32 deg., 30 min. For materials, either cohesionless or cohesive, which show a characteristic dropping off of the shear stress after the maximum has been reached, design should be based on the more conservative value of the angle of friction obtained from the ultimate strength. For designs based on the maximum value, progressive failure and the consequent dropping off of the shearing strength would create a serious situation.

The approximate volume-change relations accompanying shearing as influenced by the initial voids ratio and the normal pressure are shown in Fig. 4(*b*). The critical density, as defined by Casagrande (**4, 5**), is indicated approximately by the vertical line of zero volume change; that is, the voids ratio at the maximum shearing stress is the same as the initial voids ratio. It is evident that the critical density is a function of the normal pressure N, decreasing from about 0.74 under a normal pressure of $\frac{1}{4}$ kg. per sq. cm. to about 0.63 under 2 kg. per sq. cm.

Although the results of these series of tests are not entirely consistent nor conclusive, the thickness of the sample appears to have an appreciable influence on the value of the angle of friction, the value tending to be smaller for the thick samples than for the thin ones. It also appears from a study of the results that the 0.30-in. samples were too thin for the complete development of the usual thickness of the shearing zone.

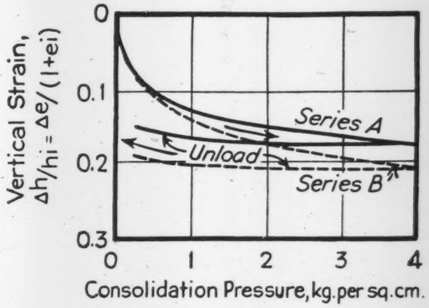
Thickness of Samples, in.	ϕ, Dense	ϕ, Loose
1.05	42° 45′	32° 25′
0.30	44° 30′	35° 30′
Mean line all thicknesses	43° 30′	33° 30′
Voids ratio	0.49	0.66

In the loose state the mean line of S/N is a straight line passing through zero, indicating that the value of ϕ is constant and independent of the magnitude of the normal pressure. In the dense state, however, either the mean line is a straight line which makes an intercept on the shear stress axis, or it is a curve. Assuming the first case, since Ottawa sand has no cohesion, this may be due to an interlocking effect of the grains in the dense state. Assuming the second case, the angle of friction is a function of the normal pressure. Computing the value of ϕ for each normal pressure separately from Eq. 1, it is found to decrease from 50 deg., 10 min. under a light normal pressure of $\frac{1}{4}$ kg. per sq. cm. to a value of 42 deg., 45 min. under normal pressure of 2 kg. per sq. cm. The curves of Fig. 4(*a*) for the dense state also show this effect clearly. The value of S/N at the peak is greater for light normal pressures than for the heavier pressures. This effect has been noted and discussed by Taylor and Leps (**1**).

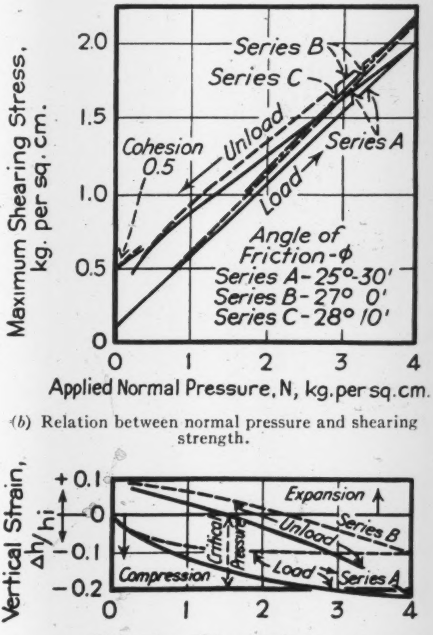
Although the initial voids ratio, initial thickness of the sample, and the volume changes during shear were measured very carefully, the results still show inconsistencies. These inconsistencies may result from secondary effects inherent in the direct-shear test method, partly because the size, shape, and any tilting of the shear box may affect results, and partly because of the large shearing deformations required to reach the ultimate shearing strength. Because of the progressive nature of the development of shearing resistance along the shearing plane in a shear box, the state of stress in the shearing plane cannot be known exactly. For these reasons the true angle of friction is not obtained, though probably not greatly in error. The direct-shear test method is not an entirely satisfactory one for determining the shearing characteristics of granular cohesionless materials, and the consistency of results is not as good as desirable.

Shear Tests on Detroit Clay:

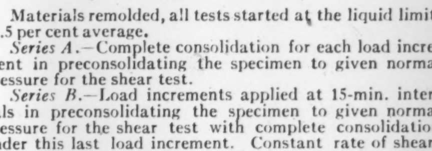
The Detroit clay represents a plastic cohesive material having a liquid limit of 25.5 per cent average and a plasticity index of 8.0. The tests on sample P-1 were a part of a study to determine the shearing characteristics of the material in the remolded state and the consistency of the results obtained by the direct-shear test method. For the series of shear tests on the Detroit clay, the material was completely remolded and brought to the state and moisture content of the liquid limit. Care was taken in placing the material to prevent inclusion of entrapped air. A special screed was used so that all samples had the same initial thickness, 0.75 in. This thickness was accurately determined by means of a straddle gage and an Ames dial after the porous stones were placed and just before preconsolidation to the desired normal pressure.



(*a*) Consolidation curves, shear box.



(*b*) Relation between normal pressure and shearing strength.



(*c*) Stress-volume change relations during shearing.

FIG. 5.—Shearing Characteristics of Plastic Gray Clay. Sample P-1, Detroit, Mich.

Materials remolded, all tests started at the liquid limit, 25.5 per cent average.

Series A.—Complete consolidation for each load increment in preconsolidating the specimen to given normal pressure for the shear test.

Series B.—Load increments applied at 15-min. intervals in preconsolidating the specimen to given normal pressure for the shear test with complete consolidation under this last load increment. Constant rate of shearing strain type of shearing loading, average rate 0.06 in. per min.

Series C.—Very slow shear test, 36 hr., Series A consolidation.

Two series of the program of tests were completed in order to determine, first, whether the rate of consolidation loading had an appreciable effect on the voids ratio attained under the desired normal pressure and on the angle of friction obtained in the shear test. In series A complete consolidation was permitted between each load increment (24 hr. interval) in preconsolidating the specimen to the given normal pressure for the shear test, just as in the regular consolidation test. In series B the load increments were applied at exactly 15-min. intervals in preconsolidating the specimen, but permitting complete consolidation under the last load increment for the normal pressure. The final voids ratios attained for each normal pressure by the two methods are plotted in the consolidation stress-strain curves of Fig. 5 (*a*). It is important to note that there is a very appreciable difference in the compression and therefore in the resulting voids ratios and moisture contents. The rapid loading appears to have almost a dynamic shock effect, similar to the effect of a shock or jar on the compression of granular materials, so that the volume change is greater and the material is in a more dense state.

In order to establish the relation between shearing strength and applied normal pressure, a series of tests was made at preconsolidated pressures of $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, and 4 kg. per sq. cm., as shown in Fig. 5 (*b*). A linear relation exists, which for the natural state of consolidation, practically passes through the origin. This means that a plastic soil, usually considered to be cohesive, behaves essentially the same as a cohesionless material having no inherent cohesion, when the material is tested in a natural state of consolidation and starting from the liquid limit. Therefore Coulomb's simple equation, Eq. 1, for cohesionless materials applies for materials in a natural state of consolidation. However the angle of friction is considerably less than that for Ottawa sand in the loose state.

As might be expected because of the smaller voids ratio and moisture content, the angle of friction is greater for series B than for series A, being 27 deg., 0 min., and 25 deg., 30 min., respectively. In series A and B the shearing load was applied so that a constant rate of shearing deformation of 0.05 in. per min. was obtained. These results show that a rapid consolidation loading does not represent the *natural state of consolidation* and does not yield a consistent value for the angle of friction, but a value higher—in this case by 1 deg., 30 min. for the Detroit clay. This difference will vary for different materials and for different rates of consolidation loading. Therefore it may be concluded that any method of preconsolidating the sample to the desired normal pressure other than complete consolidation between successive load increments tends to make the angle of friction higher than it should be by an unknown and variable amount and therefore should not be used in determining the shearing characteristics of cohesive plastic soils.

For cohesive plastic soils the researches of Terzaghi (**8**, **9**), Jurgenson (**10**), and Hvorslev (**11**, **12**) have given us a much better understanding of the shearing phenomena and the important role that the consolidation characteristics play. The outstanding physical concept introduced by these investigators is that the ultimate shearing failure and the deformations of a soil subjected to shearing forces are governed, not by the total externally applied stresses, but by the effective stresses, transmitted by grain-to-grain contacts, that is, the intergranular stresses. In cohesive soils and in fairly impermeable cohesionless soils, either in a state of incomplete consolidation or under *rapid shearing*, the volume changes which are always associated with consolidation and with shearing deformations tend to take place so rapidly that hydrostatic stresses are induced in the pore water. These hydrostatic stresses in a rapid shear test cannot be dissipated during the test by the escape of excess pore water (or by inflow) because of the impermeability of the material. Hence the externally applied pressure is carried partly by the soil and partly by hydrostatic stresses. The pore water stress is positive, if there is a tendency for volume decrease during shearing; that is, the pore water is put under compression and carries part of the external load. On the other hand, if there is a tendency for expansion during shearing, the pore water stress is negative and the tensile stresses induced in the water exert an additional pressure on the soil mass, giving it greater strength. The angle of friction, computed on the basis of total stresses, is too low in the first case and too high in the second, the values obtained depending on the rate of shearing, the moisture content, the load history of the specimen, and the consolidation characteristics of the material.

But both of these conditions are temporary. Since the pore water itself cannot transmit any part of the shearing stress, it is only the effective stresses that govern the condition of failure and Coulomb's law becomes

$$S = (N - W) \tan \phi \ldots\ldots\ldots (2)$$

where the effective normal pressure is the total applied normal pressure reduced by the hydrostatic stress, W, in the pore water at the time of failure.

As a result of extensive investigations Terzaghi and Hvorslev have concluded that the true angle of friction of a material can be determined only by a very slow shear test in which the stresses are completely known. Since the test is run so slowly that the volume changes associated with shearing action can fully take place, there exists a state of complete equilibrium of stresses at all stages of the shear test and the hydrostatic stresses are at all times equal to zero. The value of the angle of friction so obtained is the maximum value for the natural state of consolidation, being 28 deg, 10 min. for the Detroit clay in series C. The difference between this value and that for series A run at a constant rate of shearing strain of 0.05 in. per min. depends on the consolidation characteristics of the material, that is the rate of consolidation during shear. Since the average of consolidation is rather high for this material, the coefficient of consolidation being 0.015 sq. cm. per min., there is only a difference of 2 deg., 40 min. between the values of the angle of friction for the slow shear test of series C and that of a fairly rapid shear test of series A. There is also a marked difference in the form of the shearing stress - horizontal deformation curves for series A and C as shown in Fig. 6.

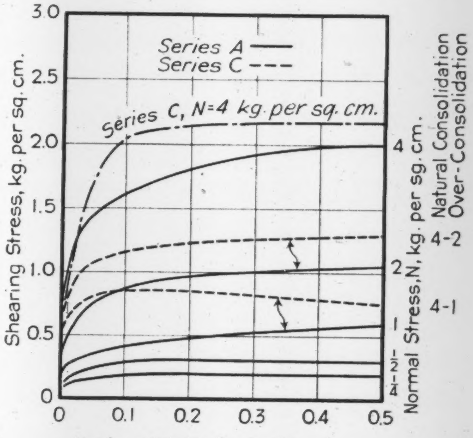


FIG. 6.—Shearing Characteristics of Detroit Clay.

The amount of consolidation occurring during shear is indicated by the volume-changes shown in the stress-volume relations of Fig. 5 (*c*). A considerable volume decrease has taken place during shearing for the material in a natural state of consolidation, indicating that with the escape of some of the pore water the hydrostatic stresses had been reduced. However, all tests made at a more rapid rate than the slow shear yield lower intermediate values of the angle of friction with unknown effective stresses acting, which cannot as yet be evaluated because the magnitudes of the hydrostatic stresses are not known. Because it is difficult to evaluate the effective stresses in all such cases, resort has been had to the use of total stresses. But this has led to misinterpretation of shear test results with inconsistent and variable values of the angle of friction depending on the rate of shearing, the consolidation characteristics of the material, and other factors.

Next a series of tests was made for series A and B in a state of overconsolidation, that is, the material was in every case first preconsolidated under 4 kg. per sq. cm. pressure, and then successively unloaded in a series of tests to 2, 1, $\frac{1}{2}$, and $\frac{1}{4}$ kg. per sq. cm. After expansion and resaturation under these pressures, the samples were subjected to the shear test. The unloading cycle of the consolidation curves is shown in Fig. 5 (*a*) and is characteristically much flatter than for the primary loading curve. The unloading cycle for the shearing strength - normal pressure curve stands in a characteristic position with respect to the primary loading curve. The curves of Fig. 5 (*a*) and (*b*) complete two branches of the loading cycle for consolidation and shear, namely, the primary compression branch and the unloading branch with 4 kg. per sq. cm. as the maximum preconsolidated load in this case. This represents the load history of the test series. Again series B yields a higher value of the angle of friction than series A, as shown by the steeper slope in Fig. 5 (*b*).

In a state of natural consolidation Coulomb's simple equation for cohesionless materials applies, either Eqs. 1 or 2. In a state of over consolidation (unloading branch of curve) Coulomb's more general equation applies

$$S = C + N \tan \phi' \quad \ldots\ldots (3)$$

where:

C = the cohesion, and
ϕ' = the angle of friction obtained by using total stresses.

In the application of Coulomb's equation to cohesive soils, Terzaghi (8) and Hvorslev (11) have demonstrated that this simple law is valid only under certain special conditions, and that the moisture content relations, the load history, and the effective stresses are competent to explain all shearing phenomena in cohesive soils, which have been obscure and difficult to interpret. The values of the angle of friction and cohesion are then determinable and consistent. Coulomb's equation then takes the form

$$S = f(C) + (N - W) \tan \phi \quad \ldots (4)$$

where:

$f(C)$ = a cohesion function, depending on the moisture content and the load history of the sample,
ϕ = the true angle of friction, and
$(N - W)$ = the effective stresses.

Cohesion is not a simple inherent constant physical property for a given soil, as first supposed, but is now known to depend on the initial moisture content for the natural state of consolidation and the subsequent load history of the sample. In series A the load history is expressed by the primary loading and the unloading branches of the consolidation curve of Fig. 5 (*a*) with 4 kg. per sq. cm. as the maximum preconsolidated load and for a rate of shearing strain of 0.05 in. per min. The shearing characteristics for series A and C (incomplete) are as follows:

State of Consolidation	Cohesion, kg. per sq. cm.	Angle of Friction
Series A:		
Natural	0 (practically)	25° 30′
Overconsolidation (4 kg. per sq. cm.)	0.5	20° 35′
Series C:		
Natural	0 (practically)	28° 10′

Considering the volume-change relations for the Detroit clay for the unloading cycle, in contrast with the results in a natural state of consolidation, there is a tendency for expansion during shearing as shown in Fig. 5 (c), and the pore water is thereby put in tension, which increases the total externally applied stresses. But this condition is temporary and such stresses would be dissipated during a slow shear test. This means that the volume changes would be somewhat larger in a slow shear test. Under these circumstances the shearing stresses are larger than they would be if effective stresses obtained in the region where expansion occurred during shear, and smaller in the region where compression occurred during shear. This in effect rotates the ϕ line so that the value of the cohesion is larger and the angle of friction is smaller (the curve is flatter) than that obtained by a slow shear test, in which effective stresses acted throughout the test. Hence for a state of overconsolidation inconsistent and variable values of cohesion and angle of friction are obtained for all shearing rates except a very slow shear test.

It may be concluded that the first requirement for obtaining reliable information on the shearing characteristics of cohesive soils by the direct-shear method is to permit complete consolidation between each successive load increment in preconsolidating a specimen to the given normal pressure for primary loading and reloading branches of the consolidation curves and complete expansion and resaturation for the unloading branches of the curves. The second requirement is to conduct the shear test at a slow enough rate so that complete equilibrium condition and effective stresses obtain throughout the test. Therefore the stress conditions are known. The third requirement is to make such a series of tests as to define the primary loading, unloading, and reloading branches of the loading cycle for some selected maximum preconsolidated pressure for the given material in order to determine for a set of known conditions the values of the cohesion (if it exists) and the angle of friction and the behavior characteristics of the material in shear.

The practical significance of these tests on remolded materials is that they give us a better understanding of the shearing characteristics of undisturbed soils and provide a clue for the interpretation of the results of the shear tests. The undisturbed soil in the ground in a natural state of consolidation differs in one very important respect from the remolded material in that it possesses an *inherent structure*. In determining the shearing characteristics of undisturbed soils one must consider two cases. The most common one is that of a soil in a natural state of consolidation in which the preconsolidation load (maximum pressure under which the soil has been completely consolidated) is equal to the weight of the overburden present. When an undisturbed sample is taken from a boring and prepared for test, the material expands on the unloading consolidation curve to zero load. In determining the shearing characteristics of undisturbed samples for normal pressures less than the preconsolidation load, one is operating on the reloading cycle of the consolidation and shear curves. The values of the cohesion and angle of friction so obtained are not representative of conditions of the soil in the natural state. Stress conditions equivalent to those in the natural state do not obtain until the normal pressure is made equal to the preconsolidation load. For greater normal pressures the reloading curve becomes tangent to the primary loading curve and one is again operating on the primary loading curve. It is only the primary loading branches of the consolidation and shear curves above the preconsolidation load that are approximately representative of conditions of the soil in the natural state or any subsequent state due to externally applied loadings.

For many soils in a natural state of consolidation, this primary loading curve practically passes through the origin in a similar manner to the curves for remolded materials as shown in Fig. 5 (*b*), and the cohesion is practically zero. Coulomb's simple law expressed by Eq. 2 applies. However, the value of the angle of friction for undisturbed materials is less than that for the remolded material, because for the same normal pressure the voids ratio and moisture content are greater for the undisturbed material.

The second case is that of a soil in a state of overconsolidation, which is a quite frequent one. The soil has, at sometime in its load history, been consolidated under much higher pressures than due to the present overburden. This condition may result from the erosion of part of a greater overburden, or other causes. This is also true of artificially compacted soils by tamping, rolling, etc. In this case one is operating on the reloading branches of the consolidation and shear curves. The portion of the curve above the pressure equal to the weight of the overburden (or equivalent compacting pressure) is approximately representative of conditions in the natural state. Coulomb's more general law as expressed by Eq. 4 applies and the cohesion and angle of friction are obtained from the reloading branches of the shear curve.

The problem in each case is to set up the test conditions, which are as nearly as possible representative of conditions in the natural state. This requires not only properly conducted consolidation tests to determine the preconsolidation load and consolidation characteristics of the material, and shear tests to establish the behavior characteristics of the material in shear, but also a correct interpretation of the test results in order to obtain values of the cohesion and angle of friction which are consistent and representative.

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THE SHEARING RESISTANCE OF SOIL—ITS MEASUREMENT AND PRACTICAL SIGNIFICANCE

By W. S. Housel[1]

Shearing resistance is one of the most important of the physical properties of soil and yet one is likely to be amazed and confused by the variety of answers which leading investigators would give to the single question of "what is shearing resistance?" Objectively shearing resistance is the resistance of material to tangential displacement under the action of tangential forces. Any soil subjected to such a test either would or would not possess this resistance and there would appear to be no particular experimental difficulty in determining its magnitude.

It is possible to differentiate quite clearly between objective and subjective attributes of shearing resistance of soil by strict adherence to the meaning of these terms. As a starting point it may be said that soils may first be considered in two large groups of granular and cohesive soils. A granular soil is one in which the particles are too large to be noticeably affected by molecular forces of attraction and repulsion. A cohesive soil is one in which the particles cohere or stick together under the influence of these same molecular forces.

Both cohesive and granular soils possess shearing resistance in the objective sense which may be reduced simply to resistance to tangential displacement under the application of tangential force. The proof of this is not difficult, it being simply a matter of applying the definition. The experimental technique of applying the force and measuring the displacement may be simple and direct. It should demonstrate clearly whether any given soil has such resistance and should determine its magnitude.

Beyond this point, however, the problem becomes more intricate and in many respects uncertain due to the introduction of speculative concepts of behavior which are necessary to a more complete understanding of the mechanisms involved in shearing resistance. Before shear test data can be used in predicting soil behavior under practical conditions it is necessary to establish the interrelationship of shearing resistance and moisture content, normal pressure, bearing capacity or ability to support loads, dimensional effects, and numerous other attributes and conditions which affect soil behavior. The introduction of some mechanism to describe these phenomena is the only method by which further progress can be made, and it is at this point that diverging viewpoints originate and controversy arises. In the author's opinion it is most important that every student of soil mechanics clearly mark this boundary between fact and hypothesis and be on guard against accepting speculative concepts as factual evidence.

It is at this point also that it becomes necessary to differentiate between cohesive and granular states, as their different characters may require entirely different mechanisms to describe their ability to resist shearing displacement.

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[1] Associate Professor of Civil Engineering, University of Michigan; Research Consultant, Michigan State Highway Dept., Ann Arbor, Mich.

COHESIVE SOILS

In purely cohesive soils it may be conceived that shearing resistance is due entirely to cohesion. As a matter of fact, shearing resistance is quite generally accepted as the measure of cohesion, the two terms being used more or less synonomously in general practice. In the field of strength of materials the maximum shear theory seems to be more generally acceptable than others, particularly as related to ductile or plastic materials and certainly in connection with those materials incapable of more than negligible resistance to tensile stress.

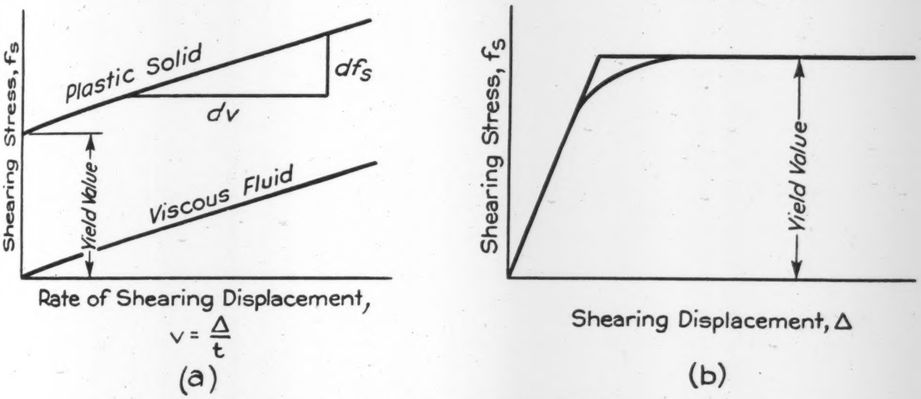

FIG. 1.—Properties of Plastic Solids.

It seems sufficient to describe shearing resistance in such materials by defining cohesion as that property of a material which produces resistance to displacement by the mutual attraction between particles involving forces of molecular origin, characteristic of microscopic and submicroscopic matter. This definition is intended to include all molecular forces, for example both adhesion and cohesion as ordinarily defined. For the purpose of discussing cohesive soils, attention may be focused on plastic solids as typical of such soils.

James Clerk Maxwell is generally credited with being the first authority to formulate an adequate description of the behavior of plastic solids and his views appear to have been quite generally acceptable to modern investigators.[2] The following definition by Maxwell is quoted by Bingham and can scarcely be improved upon:

> "If the form of a body is found to be permanently altered when the stress exceeds a certain value, the body is said to be soft or plastic and the state of the body when the alteration is just going to take place is called the limit of perfect elasticity. If the stress, when it is maintained constant, causes a strain or displacement which increases continually with time, the substance is said to be viscous.
>
> "When this continuous alteration of form is only produced by stresses exceeding a certain value, the substance is called a solid, however soft it may be. When the very smallest stress, if continued long enough, will cause a constantly increasing change of form, the body must be regarded as a viscous fluid, however hard it may be."

The measurable magnitudes which

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[2] E. C. Bingham, "Fluidity and Plasticity," McGraw-Hill Book Co., Inc., New York City (1931).

may be associated with plastic solids are illustrated in Fig. 1. In part (*a*) the plastic solid is compared to a viscous fluid and the relation shown between shearing stress and rate of shearing deformation. In the plastic solid the rate of shearing displacement is zero for a shearing stress less than the indicated yield value. For shearing stress greater than the yield value the rate of displacement, v, increases in direct proportion to the amount of stress in excess of that value. In that range of load the material behaves as the viscous fluid which is also shown passing through the origin. In Fig. 1(*b*) the behavior of a plastic solid is indicated in relation to the behavior of solids. The shearing displacement, Δ, refers to the total deformation for any given shearing stress. When the stress is less than the yield value the displacement is within the elastic range and static equilibrium is established. When the yield value is exceeded the total deformation becomes infinite when the time, t, is unlimited.

It should be pointed out that in the above definitions the representations of shearing resistance have not departed from measurable magnitudes. While bordering on subjective concepts of behavior no speculative mechanism has yet been introduced. The existence of molecular forces may be accepted as a reality, and the definite yield value either does or does not exist as determined by experimental observation. It must be admitted, however, that the discussion so far contemplates a material which maintains its individual identity and suffers no change during the observation. No provision is made for changing moisture content due to consolidation under normal pressures acting on the element of mass subjected to shearing displacement, and it is assumed that shearing resistance is a function of cohesion independent of normal pressure.

Apparent Cohesion:

In attempting to establish some relationships which will encompass such changes in the material during stress application, two behavior concepts have been introduced into the mechanics of cohesion which depend primarily on speculative mechanisms. These two attributes are generally known as "apparent cohesion" and "true cohesion."

Apparent cohesion has been introduced into soil mechanics literature by Terzaghi who summarizes his conceptions of the cohesion of clay as follows:[3]

> "The cohesion of clay is due to two factors. One of these is the pressure exerted by surface tension of the capillary water, a force whose intensity exceeds all other forces the earthwork engineer has to deal with. It may amount to several hundred atmospheres; it compacts loose, colloidal sediments more thoroughly than can be done by artificial means except in the laboratory by using a high-power testing machine. Swelling of clay is nothing more or less than the purely elastic expansion produced by the elimination of the surface tension of the capillary water. Local evaporation of the capillary water or local flooding of the surface of clay deposits produces secondary stresses, the intensity of which is far greater than the weight of the heaviest structures and which were found to be the primary cause of many vast soil displacements, known as earth slips.
>
> "The second one of the factors mentioned consists in the fact that the properties of water contained in voids of width less than 0.0001 mm. are no longer identical with those of ordinary water. In such voids, viscosity and surface tension are increased (in inverse proportion to the diameter of the voids) and the water loses its ability to evaporate in contact with air. Thus the capillary water of the clays is to a certain degree solidified by the influence of the forces exerted by the molecules of the solid matter. Due to this fact the capillary

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[3] K. Terzaghi, "Compressive Strength of Clay," *Engineering News-Record*, Vol. 95, November 12, 1925, p. 796.

pressure assumes far greater values than it would if the surface tension of the capillary water had its normal value."

While the two types of cohesion thus described are generally known as "apparent cohesion" and "true cohesion," it is interesting to note that both are described in terms of the mechanism of surface tension. The only recognition of the direct influence of molecular forces identified with adsorbed moisture is in the increased viscosity and surface tension of water in fine-pored media.

Other investigators differentiate more clearly between apparent cohesion and true cohesion and identify true cohesion as molecular reactions transmitted through adsorbed moisture films and not necessarily involving the surface tension mechanism. One form of this concept is presented by Hvorslev as follows:[4]

> "As indicated by its name, the main property of a cohesive soil is the possession of the so-called true cohesion in contrast to the apparent cohesion, caused by capillary and flow pressures, which also appears in cohesionless soils. Furthermore, the cohesive soils are generally able to undergo plastic deformations. According to current conceptions, these properties are mainly due to the content of minute particles of certain minerals, the so-called clay minerals. Due to their crystal structure these particles have the form of flakes and are able to attract and orient the bi-polar water molecules in such a manner that the water changes its original properties; the density and the viscosity increases the closer we come to the surface of the flaky particles. The particles may be said to be surrounded by films of partly solidified water. When these films overlap, certain internal forces are created and bind the particles together. We do not yet know the exact nature of these water films and the forces they create, and the above conception is just a rough working hypothesis."

There are several aspects of the surface tension mechanism as the origin of cohesion which deserve critical examination. Apparent cohesion in this connection accepts surface tension as a physical reality instead of a mathematical device substituted for the actual forces which give rise to free surface energy. This concept also postulates tensile resistance of capillary water of a high order of magnitude, and strangely enough at the same time denies that water has any shearing resistance. For example, Casagrande states:[5] "after all it is shearing resistance of soils which makes it possible to found a structure on, or to build an embankment of a mass of individual grains which are not cemented together. We cannot attempt to use water for this purpose because it has no shearing resistance."

A familiar method of illustrating the effect of surface tension is to evacuate a rubber bag filled with pebbles or dry sand. The effect of introducing the tensile forces in this membrane analogy may appear to the uninitiated to be a spectacular demonstration of a fundamental principle. It may also be used as an apt illustration of the danger of using an analogy as a basic mechanism for describing physical behavior.

In contrast to this viewpoint, authorities in physics and physical chemistry are emphatic in pointing out, and the evidence is quite conclusive, that there is no contractile skin on liquid surfaces and that in reality there can be no tensile stress. Adam makes quite clear the character of surface tension as a mathematical device for dealing with problems involving surface energy and points out the danger in mistaking it for a physical reality in the following quotation from his text:[6]

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[4] M. J. Hvorslev, "The Shearing Resistance of Remolded Cohesive Soils," *Proceedings*, Soils and Foundation Conference, U. S. Engineer Dept., June, 1938.

[5] A. Casagrande, "The Shearing Resistance of Soils and Its Relation to the Stability of Earth Dams," *Proceedings*, Soils and Foundation Conference, U. S. Engineer Dept., June, 1938.

"The great convenience of the hypothesis of surface tension, as the equivalent of free surface energy, combined with the fact that it was in use nearly a century before the conception of energy became definite, has given the words 'surface tension' a predominance in the literature of surfaces, which does not rightly or logically belong to them. The term 'surface tension' has often been strained to imply that liquids have in their surfaces some mechanism like a stretched membrane pulling parallel to the surface. The surface is said to be in a 'state of tension.' This view must not be pushed too far. Any mechanism possessing free energy in the surface will undergo the spontaneous contraction which has led to the idea of surface tension; hence we can gain practically no idea of the actual nature of the mechanisms in the surface, from this fact of spontaneous contraction alone. The view that there is some skin in the surface, pulling parallel to it, leads to great difficulties when the structure of the supposed skin is considered in terms of molecules.

"On molecular theory, positive surface free energy or surface tension, is due to an inward attractive force, exerted on the surface molecules by the underlying molecules. There is no special force between the surface molecules, pulling parallel to the surface * * * * * *

"Attempts to explain the surface phenomena of pure liquids in terms of a pull parallel to the surface are still rather frequent; and two other aspects of these attempts may be noticed. Some writers suggest that the surface molecules have their force-fields so deflected as to form a kind of linked skin in the surface, the attractions of the surface molecules being directed along the surface instead of equally in all directions. Apart from the fact that such a deflection of the force-fields would be difficult to account for unless the molecules were capable of a very special orientation in the surface, it would seem that this closely knit skin would be a hindrance, rather than a help, to the contraction of the surface; for the essential occurrence when a surface contracts is that molecules are expelled from it, and a particularly strong linkage between the surface molecules would tend to keep them in the surface. This is a fair specimen of the contradictory nature of theories which are based on a desire to ascribe a physical reality to the purely mathematical device of surface tension.

" * * *The essential mechanism, even on Laplace's theory (which subdivides the liquid indefinitely) of the production of the free surface energy, is the perpendicular inward attraction, exerted on the surface molecules by the underlying ones; there is no need to speculate how this can be transformed into a surface tension parallel to the surface, for the surface tension does not exist as a physical reality, and is only the mathematical equivalent of the free surface energy. The mathematical device will always be available as a substitute for this free energy, whatever the mechanism by which this energy is produced molecularly; it can, therefore, never tell us anything about the mechanisms at the surface."

Corollary to the use of the surface tension analogy in the mechanics of cohesion is the concept of the soil-water system as two discontinuous phases in which the soil particles are pictured as an independent framework with free water filling the void space and held in the mass only by surface tension. There follows the introduction of "effective stress" as distinct from total stress, it being conceived that an element of mass subjected to pressure will divide the total pressure between the solid framework and hydrostatic pressure in the voids. On the basis that the free water cannot withstand any differential pressure under conditions of static equilibrium it is considered that due to consolidation the hydrostatic pressure difference is gradually transferred to the solid framework as the water is squeezed out. Any difference in principal pressures which gives rise to shearing stress in the element is relegated to the role of internal friction, there being no recognition in this development of true cohesion due to molecular forces in the adsorbed water. Thus apparent cohesion and the conception of the soil-water system as two separate phases is founded on a speculative concept rather than a physical reality. While the use of surface tension has been tolerated as a mathematical device, the warning has been given that it is dangerous ground to build upon. Its use in the mechanics of cohesion is the real source of controversy between two rather definitely opposed schools of thought in soil mechanics.

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[6] N. K. Adam, "The Physics and Chemistry of Surfaces," Oxford University Press, London, England (1930).

In the author's opinion apparent cohesion based on the conception of cohesive soils as a system of two separate phases consisting of a framework of soil particles and voids filled with water introduces several outstanding inconsistencies. In the first place, the whole theory collapses completely for those soils in which the voids are not filled with water and, as a matter of fact, its supporters clearly state that it applies only to saturated soils. What then of those cohesive and plastic soils which are not saturated? They have shearing resistance due to cohesion as defined; their consolidation under normal pressures apparently differs very little, if any, from saturated soils.

In the second place, the volumetric analysis of many clay soils, regardless of whether they are saturated or not, indicates that the quantity of adsorbed moisture is such that the voids in the mass are considerably in excess of the voids in a granular mass in the loosest state. In other words, mechanical stability or internal friction cannot play more than a negligible part in their resistance to displacement because the particles are prevented from making contact by the intervening moisture films. These observations are common experience in all clays and the possibility of a flocculated structure to form the independent solid framework capable of carrying the so-called effective stress appears to be nothing more than a remote possibility in the exceptional case.

In the third place, the great importance attached to surface tension as the source of cohesion capable of producing tremendous pressures is not borne out by experimental evidence. On the contrary, some investigators have been unable to discover any evidence that local evaporation or local flooding of the surface of the clay produces an effect on the bearing capacity of a clay deposit as long as the change in moisture content does not penetrate more than a negligible distance into the mass.

The practical implications of apparent cohesion and the surface tension mechanism are far-reaching. To accept it is to accept that clays have no inherent shearing resistance or cohesion and no bearing value other than pure flotation. By the same criterion no clay embankment can be in stable equilibrium except as the result of internal friction which is a function of normal pressures, and can be destroyed by the separation of particles due to adsorbed moisture films.

These conclusions would have to be accepted and are accepted by some in spite of the fact that there are many examples of saturated clay deposits carrying heavy structures which impose pressures in excess of static earth pressure and yet do not suffer progressive settlement. Load tests and laboratory shear tests demonstrate that these materials have substantial resistance at zero normal pressure, and their increased resistance due to increased normal pressures is negligible in comparison. Embankments surrounding excavations in these same materials remain in equilibrium as far as displacement is concerned up to a certain height which has no relation to the intensity of normal pressure.

In this connection the author was greatly interested in a discussion of embankment failures by Terzaghi at the 1938 Annual Meeting of the Highway Research Board. He stated that in the investigation of a number of major earth slides in Bulgaria and similarly in the analysis of earth slides by Swedish engineers, it was found that the shearing resistance mobilized on the failure surface agreed very closely with the shearing resistance at zero normal pressure as determined by shear tests.

True Cohesion:

The state of confusion and the conflict between theory and practical experience that has resulted from the widespread use of apparent cohesion and the surface tension mechanism is entirely eliminated if true cohesion in the sense that it has always been applied to cohesive materials is accepted in soil mechanics.

The mechanism involved is no different from that which has been generally accepted in other fields and is being used by several investigators in soil mechanics. As in the chemistry of surfaces it is conceived that the surface of any solid, in this case the surface of soil particles, is capable of adsorbing molecules which may become permanently attached to the surface forming adsorbed layers. Particularly with polar substances such as water, molecular orientation following adsorption may build up boundary layers many molecules in thickness. In such molecular orientation the water molecules lose their mobility in varying degrees depending on the magnitude of the molecular forces of attraction. It is entirely logical to suppose that this mechanism extends to the formation of continuous molecular chains which mark the beginning of a crystalline structure.

Thus, in fine-pored media such as cohesive soils, permanent bonds may form between adjacent particles and cohesion or static shearing resistance become a physical reality. Any soil that achieves this state, sometimes referred to as solidified water, would exhibit a definite shearing resistance which must be overcome before displacement under shearing stress could take place in the mass. Such a substance would exhibit a yield value in accordance with the definition of a plastic solid given by Maxwell, Bingham, Nadai, and others.

There is nothing in this view that conflicts with the variation in shearing resistance or cohesion with a variation in moisture content, temperature or pressure, or with the shrinkage and expansion of soils. In fact the concept of true cohesion brings much better agreement in many respects. Evaporation of soil moisture leads to decreased thickness of adsorbed layers and increased cohesion only when the decrease in moisture content has affected the entire soil mass whereas apparent cohesion would become entirely mobilized as soon as the surface was subjected to local drying. The change in cohesion may then be associated with shrinkage of the soil mass which may require a considerable time interval after the surface of the mass has become dry. As the soil mass approaches the shrinkage limit and long after the hypothetical "surface tension" must have been completely mobilized, the cohesion continues to increase and approach its maximum value.

The stage approaching the shrinkage limit also represents the condition under which the soil particles are drawn into closer contact and mechanical interlocking may give rise to shearing resistance known as internal friction. It is worthy of notice that in order to produce similar effects by the application of pressure there would be required consolidation pressures of relatively enormous magnitudes. Thus film thicknesses may be decreased with comparative ease by the removal of water by evaporation a molecule at a time. The static pressure required, however, to squeeze molecules from the adsorbed films is out of the range of the ordinary pressures of practical experience.

Thus one comes logically to the conclusion that shearing resistance due to cohesion is for all practical purposes relatively independent of normal pressures. This position is sound because the change in moisture content with increased pressure within the range of practical experience is not sufficient in a saturated soil to bring soil particles into contact. It may be added further that the pressure concentration which it is possible to develop in the indefinite mass of a clay deposit without lateral displacement is in itself limited by the shearing resistance of the soil and cannot approach the pressures which may be applied in the confined compression test.

That resistance to shearing displacement in pure cohesive materials is independent of normal pressure is consistent with the generally accepted criterion of failure given by the maximum shear theory. This relationship is illustrated in Fig. 2.

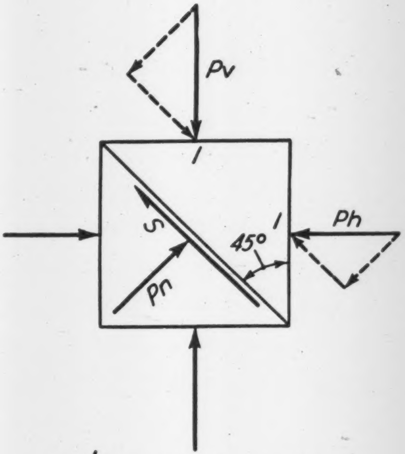
Given the principal stresses on an element of mass of which p_v is the maximum principal pressure and p_h the minimum, it may be shown that the maximum shearing stress acts on planes at 45 deg. to the principal planes and is equal to one half the difference between the principal pressures. From this, the criterion of failure may be stated as the maximum difference between the principal pressure, equal to twice the shearing resistance of the soil.

$$p_v - p_h = 2S$$

This condition is satisfied for any values of static pressure as long as the maximum difference is not exceeded and thus the normal pressure, p_n, may be increased or decreased without affecting the maximum shearing resistance.

SHEAR TESTS FOR COHESIVE SOILS

It would appear then that in cohesive soils which conform to the definition given, the measurement of shearing resistance can be reduced to a determination of the yield value of the soil. The author has for a number of years employed two simple shear tests for this purpose. The first of these has been designated as a penetration method of measuring shearing resistance and is described in detail in a paper presented before the Society in 1935.[7] This method consists of driving a standard core barrel into the soil with a standard blow and measuring the penetration per blow. The penetration per blow has been correlated with the number of blows for 6 in.



$$S \times \frac{1}{0.707} = 0.707 P_v - 0.707 P_n$$
$$S = \frac{1}{2}(P_v - P_n)$$

FIG. 2.—Criterion of Failure for Cohesive Materials.

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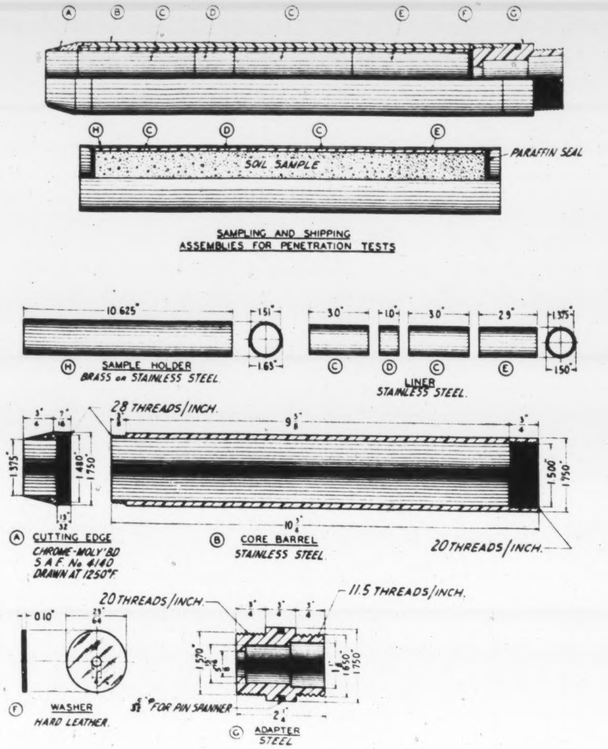
[7] W. S. Housel, "A Penetration Method of Measuring Soil Resistance," *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part II, p. 472 (1935).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Ⓗ Ⓒ Ⓓ Ⓒ Ⓔ
SOIL SAMPLE
PARAFFIN SEAL
SAMPLING AND SHIPPING
ASSEMBLIES FOR PENETRATION TESTS
10 625"
151"
1.63"
Ⓗ SAMPLE HOLDER
BRASS OR STAINLESS STEEL
30"
10"
30"
29"
1375"
150"
Ⓒ Ⓓ Ⓒ Ⓔ
LINER
STAINLESS STEEL.
28 THREADS/INCH.
3/4"
7/16"
1.375"
1.480"
1.750"
13/32"
3/8"
9 5/8"
3/4"
1.500"
1.750"
10 3/4"
Ⓐ CUTTING EDGE
CHROME-MOLY'BD
S.A.E. No 4140
DRAWN AT 1250°F
Ⓑ CORE BARREL
STAINLESS STEEL
20 THREADS/INCH.
20 THREADS/INCH.
11.5 THREADS/INCH.
0.10"
25/64"
3/4"
3/4"
3/4"
1.570"
1 1/8"
1.650"
1.750"
2 1/4"
5/32" FOR PIN SPANNER
Ⓕ WASHER
HARD LEATHER.
Ⓖ ADAPTER
STEEL

FIG. 3.—Core Barrel Assembly for Shear Test Samples of Cohesive Soil.

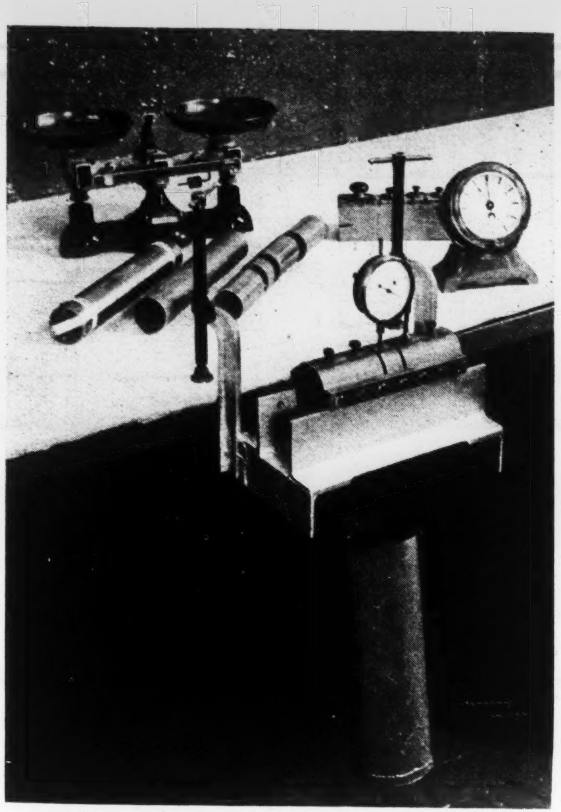

FIG. 4.—Equipment for Transverse Shear Test of Cohesive Soils.

of penetration and this index used to evaluate shearing resistance of the soil. Shearing resistance values so obtained have been correlated with load tests and with a simple transverse shear test conducted on the clay core.

This transverse shear test is the second method referred to and illustrated in Figs. 3 and 4.

Figure 3 shows the core barrel assembly used to obtain samples of cohesive soil for the transverse shear test. A sectional steel liner is inserted in the core barrel and may be easily removed without disturbing the core. The steel liner and core are inserted in a brass cylinder, the ends sealed with paraffin, and sent to the laboratory for test. The steel liner is divided into four sections consisting of one 1-in. length and two adjacent 3-in. lengths and one extra length of 2.9 in. used for supplementary tests.

In Fig. 4 is shown the assembly of equipment for the transverse shear test. That portion of the steel liner and core consisting of the 1-in. section and two adjacent 3-in. sections is transferred from the brass cylinder to a supporting cylinder and saddle. The 1-in. section is aligned with the similar removable section of the supporting cylinder so that it may be subjected to a transverse force. The shearing displacement is measured by a dial gage reading to 0.001 in. mounted as shown in Fig. 4.

The load is applied in increments of static load selected to approximate one fifth of the estimated yield value so as to provide some four or five observations below the point of progressive displacement. After each load increment the load is held constant for a period of 10 min. and deformation readings taken every 2 min. during the time interval between load increments. Enough load increments are added to cause complete failure of the specimen in shear.

In Fig. 5 is shown a typical set of test data from a shear test on a core sample of plastic clay. In Fig. 5(*a*) the shearing displacement for each increment is plotted against time showing the rate of displacement. The slope of these time

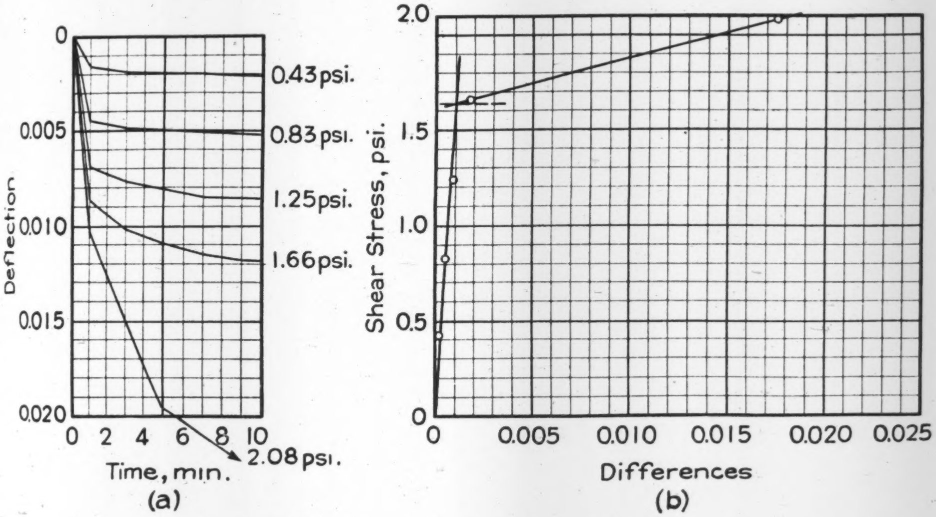

FIG. 5.—Typical Results from Transverse Shear Test.

rate curves approaches a horizontal line for the lower loads which is taken as an indication that they are approaching zero rate of displacement. For higher loads the slopes increase, there being a definite change in behavior which may be located by plotting rates of displacement against shearing stress as shown in Fig. 5(*b*).

The slopes of the time-rate curves are approximated by using the deformation for the last 7 min. of each 10-min. time interval as a measure of the slope. These differences plotted against the respective shearing stresses give one linear relationship shown by the steep line for the first few load increments approaching elastic behavior. A marked increase in the rate of displacement is found for those load increments just preceding total failure and the straight line through these points is representative of the plastic flow stage, the slope being analogous to a coefficient of viscosity. The intersection of these two straight lines is taken as the yield value and in the example shown is 1.65 psi.

In tests of this nature a considerable variation may be expected between individual samples and the shearing resistance of any given deposit should be based on a sufficient number of samples

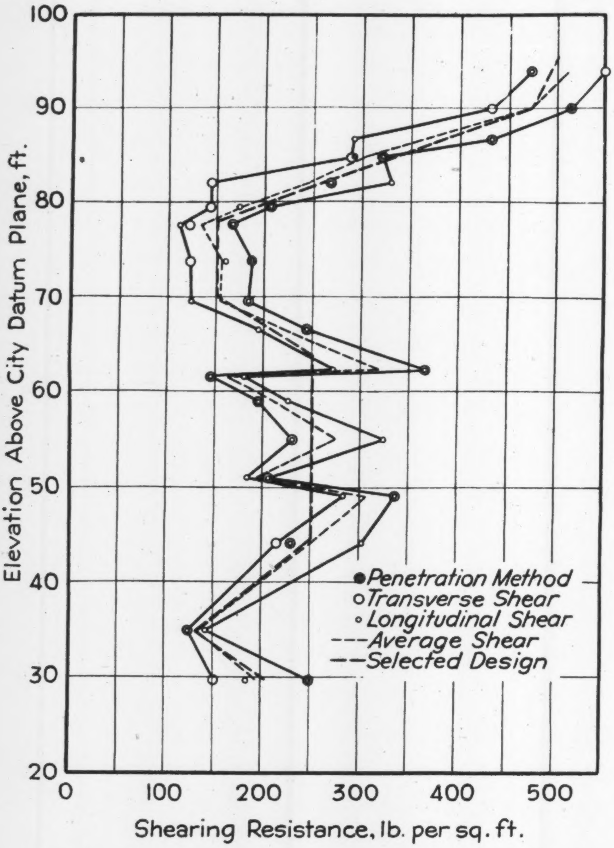

FIG. 6.—Shear Test Results for the Detroit Sewage Disposal Plant.

to fairly represent the deposit as a whole.

In Fig. 6 is shown the shearing resistance values obtained from samples taken at various depths in a clay deposit at the Detroit Sewage Disposal Plant. In this case three types of shearing resistance observations were made. The values obtained by the different methods are identified by symbol and include the penetration method, the transverse shear test, and a horizontal shear test obtained by observing the depth of penetration of the core barrel of the penetration machine for the dead weight of the core barrel and driving mechanism. In this instance the clay was so soft at certain depths that very nearly full penetration of the core barrel took place under the dead weight and it was impossible to obtain a reliable record of the penetration per blow. In these cases the longitudinal shear measurement has been found to be fairly reliable. In some cases the cores of soft clay were lost in retracting the core barrel and no transverse shear test could be conducted.

The results as a whole give a fair representation of the experimental error involved in the shearing resistance measurements described. The results obtained from the use of these values in various design and construction problems indicates that their accuracy is within the limits of accuracy in estimating loads and controlling construction procedure.

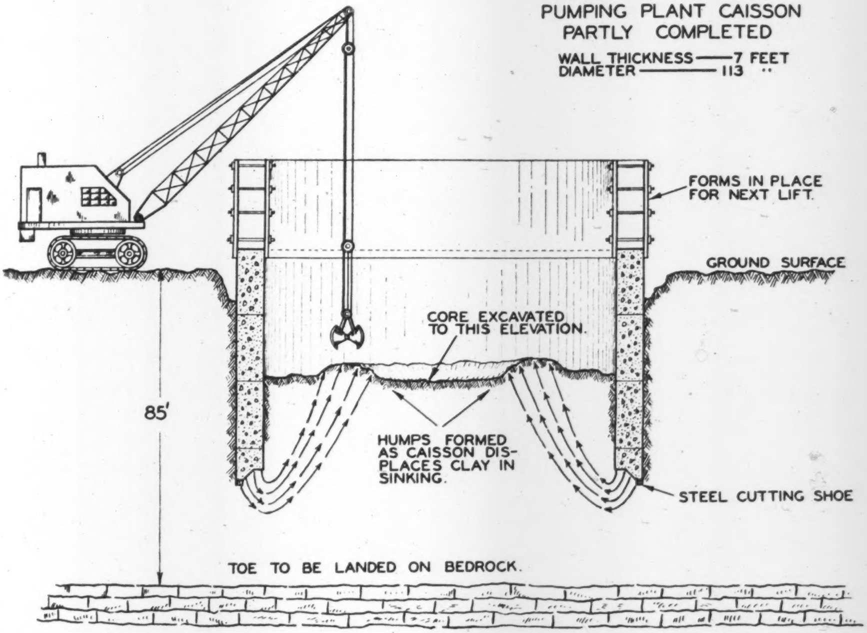
PUMPING PLANT CAISSON
PARTLY COMPLETED
WALL THICKNESS——7 FEET
DIAMETER———113 ··
FORMS IN PLACE FOR NEXT LIFT.
GROUND SURFACE
CORE EXCAVATED TO THIS ELEVATION.
85'
HUMPS FORMED AS CAISSON DISPLACES CLAY IN SINKING.
STEEL CUTTING SHOE
TOE TO BE LANDED ON BEDROCK.

FIG. 7.—Schematic Diagram of the Sinking of Large Circular Caisson.

PRACTICAL APPLICATION OF SHEAR TEST RESULTS

The shear tests previously described were made for the specific purpose of determining the procedure for sinking a 99-ft. diameter circular caisson through the clay deposit to bearing on the underlying bedrock. The depth of clay de-

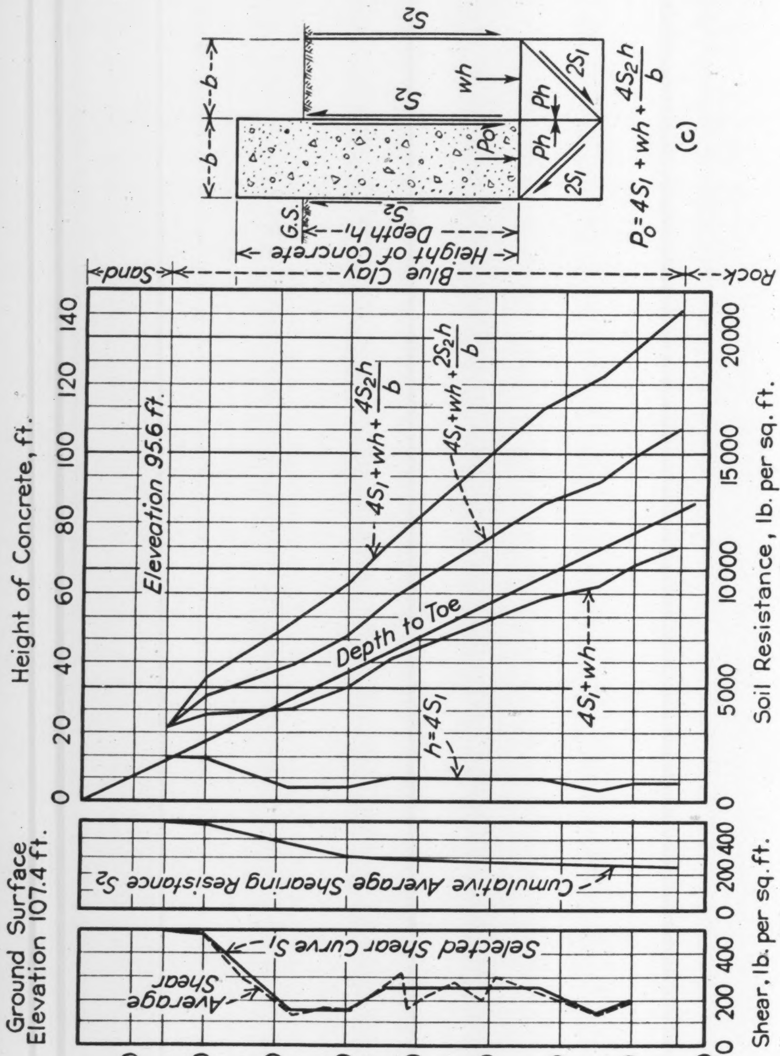

FIG. 8.—Factors of Soil Resistance in Sinking of Circular Caisson.

posit was approximately 75 ft. and there was an overburden of approximately 10 ft. of sand at the surface. The outside diameter of the caisson was 113 ft., the walls being 7 ft. in thickness. It was proposed to sink the caisson under its own weight, excavating the core on the inside as required to sink the caisson. In Fig. 7 is shown a schematic diagram of this operation.

The procedure to be followed in sinking the caisson presented two distinct problems. In the first place, it was feared that the weight required to punch through the stiff top layers of clay would be too great for the soft underlying strata and that the caisson would sink below the surface before the next lift could be poured and have time to set. In the second place, there was the possibility after the caisson had reached a certain depth that the core excavation required to keep the caisson in motion would create too large a differential between the inside and outside of the caisson and would cause inflow of the soft soil resulting in excessive upheaval inside and subsidence outside. This had been the experience on a similar caisson sunk in Detroit several years before at which time considerable damage was done and the caisson very nearly got out of control.

It was necessary to avoid either of these contingencies and at the same time the contractor wished to be able to add the successive lifts at the ground surface in sections of about 10 ft. without building form work more than approximately 10 ft. above the ground.

The solution of these problems depended primarily upon the computation of soil resistance encountered by the caisson in sinking and was based on the shearing resistance measurements shown in Fig. 6. The methods used in computing the total soil resistance are shown in Fig. 8. Part (*a*) shows the shearing resistance curve averaging the results obtained from the three methods of measurement. These results have been leveled to give a design shear curve averaging out the high and low values for comparatively thin clay strata. In part (*b*) the various factors of soil resistance are shown separately as well as being combined in a curve which gives the total resistance at each elevation.

In part (*c*) are indicated the various factors of resistance which were considered. The caisson wall is taken as a bearing area 7 ft. in width and may be treated as a two-dimensional problem for the diameter of caisson is large with respect to the wall thickness. The first factor considered is the developed pressure or resistance to lateral displacement equal to the maximum difference between the principal pressures on two elements of mass. These elements are taken as cubes with a lateral dimension equal to the wall thickness and are then considered as the unit elements. In accordance with the criterion of failure for cohesive material this developed pressure is equal to four times the shearing resistance of the soil, S_1, at the toe of the caisson. The next factor of resistance is the static head, wh, of the soil above the elevation of the toe. Inasmuch as core excavation is contemplated, the volume displacement will all be toward the inside and the static head will be measured to the top of the core. The third factor is the shearing resistance of the soil acting on the side walls and equal to the total shear for the entire depth of the clay layer down to the elevation of the toe. This total force is expressed as an equivalent pressure acting over the bearing area 7 ft. wide. The value of shearing resistance used in computation of the side wall shear is the cumulative average, S_2, for the given depth.

The fourth and last factor of resistance which comes into play is the resistance to upward displacement of the core. The resistance to upheaval has been evaluated for a vertical column of a width equal to the size of the unit element of mass or the wall thickness. The shearing resistance mobilized is the cumulative average shear, S_2, equal to the side wall shear previously used.

The total resistance is the summation of all four factors and is given by the following equation expressed as an equivalent pressure, p_o, acting over the base of the wall:

$$p_o = 4S_1 + wh + \frac{4S_2h}{b}$$

Ordinates of the total resistance curve were computed at each controlling ordinate of the shear diagram, assuming that the toe had penetrated to the given depth without any core excavation being required. The resistance curves have been plotted to two scales, the lower one being in pounds per square foot and the upper scale in height of concrete. The total resistance computed assuming no excavation indicates that the caisson could not sink of its own weight. This is shown in the diagram by the fact that the total resistance curve is at all elevations considerably in excess of the straight line which shows the depth to the toe measured from the surface. The difference between total resistance curve and the depth to the toe represents the height of concrete above the ground elevation which would be required to sink the caisson to the given elevation. This height is considerably in excess of any feasible working limits at the surface.

Actually, of course, it was anticipated that considerable excavation of the core would be required as is shown by the above comparison. For the purpose of this discussion the intervening steps in the problem of limiting the excavation to less than that critical depth at which inflow would become impending will not be presented. Attention may be given only to the problem of resistance to sinking and a comparison between the actual behavior and that predicted from the shearing resistance measurements. The objective of this comparison is to demonstrate that the simple shear tests described which are independent of normal pressure give a reliable measure of actual resistance available under practical conditions.

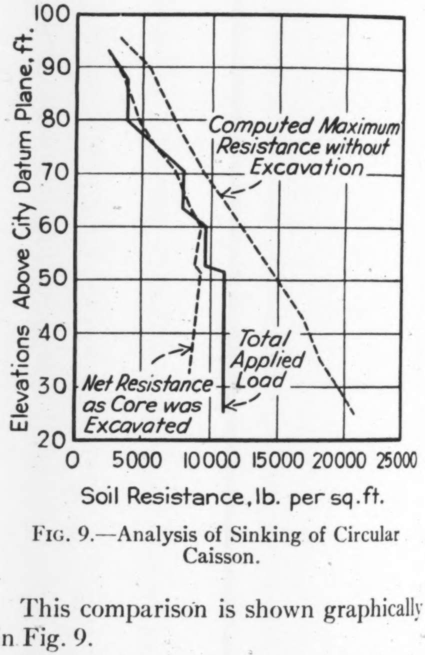

FIG. 9.—Analysis of Sinking of Circular Caisson.

This comparison is shown graphically in Fig. 9.

The total resistance curve previously shown for the assumption of no excavation is again indicated. The net resistance available has also been computed using actual core elevations after the excavation for each lift that was poured. The actual behavior is indicated by plotting the applied toe pressure due to the weight of concrete at the elevation at which the caisson came to equilibrium after each lift had been poured. The comparison between actual and predicted behavior is remarkably good down to approximate elevation 52 at which time the total height of concrete had been poured. At that point the completion of the work required only excavation of the core which was carried on continuously. During this stage the caisson was kept in motion at a rate considerably in excess of that which would mobilize the yield value shearing resistance. In other words, the rate of shearing displacement was increased and dynamic resistance of an indeterminate amount was mobilized in accordance with the laws of plastic flow.

CONCLUSION

In the foregoing discussion the attempt has been made to formulate or rather emphasize simple but logical conceptions of shearing resistance of cohesive soils which would clarify the points at issue in the conflicting viewpoints on this extremely important subject. It is significant that these conceptions are not at all new but are actually in entire accord with generally accepted ideas of cohesion in other fields.

True cohesion in accordance with the generally accepted definition and the treatment of cohesive soil as a continuous medium, rather than two phases acting independently, permits simplification of methods of measurement and the practical application of shearing resistance. To accept this viewpoint necessarily eliminates apparent cohesion and the surface tension device as a mechanism to describe cohesion. This choice must be made by the individual as there appears to be no compromise between the two conceptions. Any attempt to retain them both will only prolong the period of uncertainty and confusion. The author has definitely made this choice and it is his firm belief that the evidence available to support it is more than sufficient.

THE EFFECTS OF INTERNAL HYDROSTATIC PRESSURE ON THE SHEARING STRENGTH OF SOILS

By L. W. Hamilton[1]

The problem of shear testing has long been extremely perplexing in that widely different results could be obtained, depending upon such items as the testing procedure, size of specimens, density and moisture content of the soil, permeability of the soil, and many other variable factors. Development of a physically sound explanation of the causes of variations in results has been given much consideration by Bureau of Reclamation engineers and has resulted in the concept that internal hydrostatic pressure or hydrostatic pressure in the pore water (hereafter called "pore pressure") has an extremely important bearing upon the shearing strength of soils and that each of the factors mentioned above may cause variations in pore pressure and thus cause differences in the shearing resistance of the soil.

In the spring of 1936, the Earth Materials Laboratory and the Photoelastic Laboratory of the Bureau of Reclamation, started discussions on the problem of interpretation of shear-test data on soils as related to the design problem and also the explanation of the variations caused by different test-procedure and density-moisture conditions. A speculative explanation of the effects of entrapped air on pore pressure as related to test procedure and soil condition was evolved which led to the idea of approaching the soil stability problem from this viewpoint. Laboratory studies and experiments were started to develop a better understanding of the concept of pore pressure, with special emphasis upon its magnitude and effects. At the same time the Photoelastic Laboratory developed a mathematical procedure for the analysis of the problem.[2] This analysis is dependent upon the determination of constants as well as verification of theory by the Earth Materials Laboratory.

The idea of pore pressure and its effects on stability is not new in soil mechanics. In fact, there are numerous references to the phenomenon that are almost as old as the science itself. The writings of Terzaghi make many references to the phenomenon,[3] but detailed descriptions of the analysis, as well as supporting data, are rarely found.

There are many serious mechanical and technical difficulties involved in attempting measurements of pore pressures. At the present time, the data available are so limited that positive conclusions cannot be reached. However, a frank discussion of the problems and a discussion of the concept of pore pressure should be beneficial for a more complete understanding of the shear test. The purpose of this paper is to describe the effects of pore pressure, point out the important possibilities involved, present data and describe attempted methods to measure pore pressure, and suggest possible methods of study for determining the corrections involved.

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[1] Associate Engineer, Bureau of Reclamation, Denver, Colo.

[2] J. H. A. Brahtz, C. N. Zanger and J. R. Bruggeman, "Notes on Analytic Soil Mechanics," *Technical Memorandum No. 592*, Bureau of Reclamation.

[3] Charles Terzaghi, "Principles of Soil Mechanics," *Engineering News-Record*, Vol. 95, No. 26, p. 1029 (192

CONCEPT OF PORE PRESSURE AND ITS EFFECTS ON SHEARING STRENGTH OF SOILS

To describe the concept of pore pressure and to show its effects on the shearing strength of soils, the following factors are given consideration:

1. The shearing strength of a soil depends largely upon the contact pressure between the soil grains because the frictional resistance is proportional to this contact pressure.

2. The pressure in the pore water reduces the contact pressure between soil grains and consequently reduces the shearing strength of the soil.

3. The loading of the soil specimen in the shear test produces a volume strain which must be accompanied by either a corresponding extrusion of the fluid from the pores in the soil mass or a compression of the fluid in the pores which produces pore pressure. Thus, if the soil is of low permeability, compression of the fluid in the pores will probably result.

4. It is practically impossible to eliminate all entrapped air from a soil specimen. If the specimen is analyzed it will be found that its volume is made up of solid soil particles, water, and air. Within the normal range of loading used, both the soil particles and water are practically incompressible, while the air is compressible. Thus the volume change tends to compress the air and produces pore pressure even though the voids are not filled with water. The compressible fluid (mixture of water and air) in the pores may undergo a large or small volume change to create significant pressures, depending upon the quantity of air present; likewise, the extent of drainage in dissipating pressure may be relatively large or small. This is an important phase of the concept because the induced pore pressures are a function of both the volume change and the compressibility of the pore fluid. Since the rate of drainage is a function of the pressure head causing drainage, it is also a function of both the volume change and the compressibility of the pore fluid.

The pore pressure can be neglected only when the volume strains are so controlled that under a small pressure head the fluid will flow from the specimen at the same rate as the volume change. This restriction imposed on the test procedure for materials of extremely low permeability would increase the time required for testing to such an extent that the time element would make the tests practically prohibitive; also the volume change and corresponding drainage measurements necessary to control the tests within the restricted limits would require a degree of accuracy and a test procedure that would be difficult to obtain. Thus the results from shear tests that are uncontrolled may have little meaning except for comparative purposes.

5. The laboratory test specimens are subjected to a stress condition that may be distorted from the stresses in the prototype. For example, the loading in the structure may be gradually increased over a few months or a few years, while the laboratory specimen is loaded in a few minutes; also, the drainage of the soil in the structure may be resisted by a few feet or hundreds of feet of soil, while the drainage of the laboratory specimen is resisted only by a fraction of an inch, or, at most, by a few inches of soil. Such distortions may give test results that are either above or below the real strength of the soil in the structure. If it were practical to duplicate in the laboratory all the possible critical stress conditions

on the material in question, the pore pressure consideration could be eliminated.

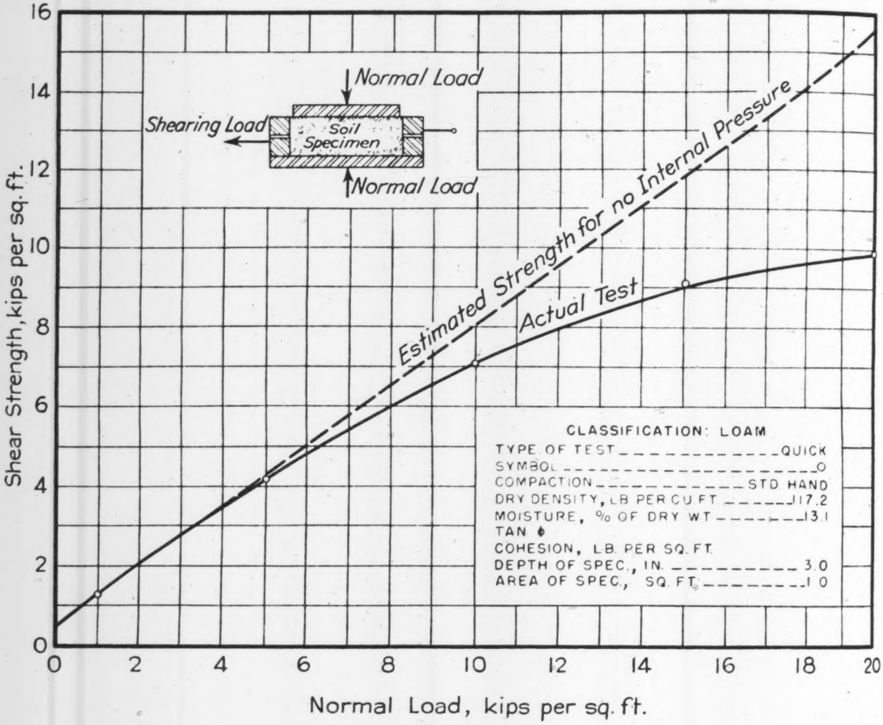


FIG. 1.—Normal Load, Shear Relations.

In view of the restrictions and conditions as discussed under 4 and 5 above and of the concept of the effects of pore pressure, it seems that the laboratory problem on shear should be divided into four parts:

First, to isolate, if possible, the effects of pore pressure and determine the potential shearing resistance of the soil without pore pressure.

Second, to determine the relationship between volume change under load and the magnitude of the induced pore pressure.

Third, to determine the coefficients of dissipation of these induced pore pressures, that is, pore pressures induced by consolidation.

Fourth, to determine the coefficients of dissipation of the pore pressure induced or created by percolating water.

Many engineers have recognized that the apparent stability of a soil depends upon numerous conditions, such as density or state of consolidation, moisture content, the rate of loading, and especially the permeability. If the concept of pore pressure is speculatively applied to the problem, it seems to give a logical explanation for the wide variations in the shearing strength of soils under different conditions and for the variations of different soils. However, before the concept can be applied on an analytical basis, the following factors should be known: first, the potential shearing resistance of the soil without pore pressure; second, how much pore pressure is formed; and third, at what rate the pore pressure will dissipate. These items are believed to be related to the character of the soil and to its state of original consolidation. The state of original consolidation is related to the soil structure, density, moisture, air content, permeability, and the initial pore pressure. All these items are so interrelated that each must be considered in stability analyses if the concept of pore-pressure effects are valid.

TEST RESULTS WHICH INDICATE PRESENCE OF PORE PRESSURE

The concept of pore pressure and its possible importance was first conceived from observations made on the standard type of direct shear tests. A brief description of the reasoning used will help to clarify the concept and be of general interest.

One of the first indications of pore pressure was that direct shear test results on soils of medium low permeability did not give a straight-line relation between the normal load applied and the corresponding shearing strength. For example, Fig. 1 shows the plotted data from a test on a loam soil. From this figure it may be noted that the shearing strength does not vary in direct proportion to the applied normal load. For the lower normal loads, the consolidation of the soil mass was small. Consequently the compression of the fluid in the pores would be so small that the pore pressure should be ineffective in reducing the contact pressure between the soil grains. Thus the experimental curve has its greatest slope in this lower range and is believed to approach the true coefficient of friction for the soil without pore pressure. On the other hand, the higher normal loads created larger volume changes, thereby compressing the fluid in the pores to such an extent that the pore pressure becomes large in proportion to the applied normal load. The facilities for drainage of the water from the above-described specimen were not particularly favorable for it was limited to the top and bottom edges of the specimen; however, similar results have been observed where the drainage conditions were favorable.

Another investigation which is believed to indicate the effects of pore pressure was a study to show the effects of placement moisture on the shearing strength of a soil of comparatively low permeability. The results of these tests are shown in Fig. 2. Specimens of this soil were compacted at moisture contents ranging from about 14 to 24 per cent by dry weight of soil. The original volume of soil, water, and air was computed using the dry weight of the soil obtained at the different moisture contents and the absolute densities of the soil and water. The data were then plotted as shown by the bottom curve on Fig. 3. Then using the measured volume changes produced by the loads shown and superimposing those on the original air volume curve, the other curves shown on Fig. 3 were obtained. It may be noted on this figure that the three higher loads actually show that the compression exceeded the initial air volume and a part of the water must have been squeezed from the specimen. Test observations indicated some appreciable drainage of the samples placed at about 19 per cent moisture and considerable drainage on those placed at 23 to 24 per cent moisture.

Next it was assumed that no drainage of air or water actually occurred from the above-described soil specimens, that Boyle's law for compression of gases held for the original air volume, and that the air in the specimen as placed was at atmospheric pressure. Based on these assumptions, the volume changes and original air contents shown on Fig. 3 were used to compute pore pressures.

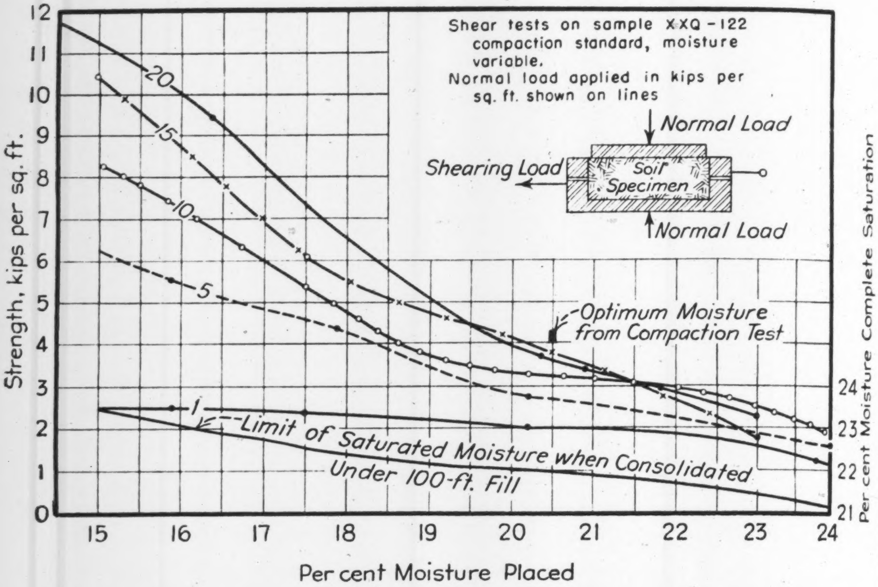


FIG. 2.—Effect of Moisture on Strength and Data for Internal Pressure Studies.

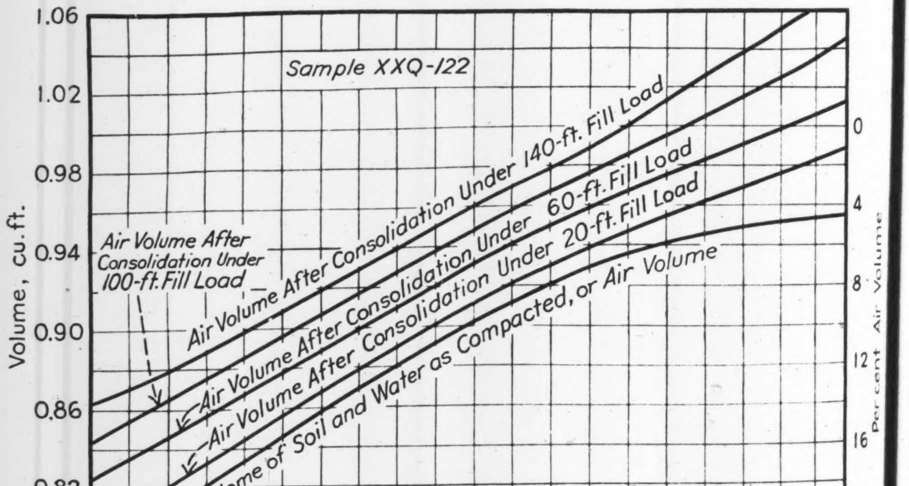


FIG. 3.—Showing Reduction of Air Volume by Consolidation, and Data for Internal Pressure Studies.

The results of the computations are plotted in Fig. 4. A comparison of Figs. 2 and 4 indicates that at the higher moistures the measured shearing strength, regardless of the normal load applied, was extremely low and that the theoretical pressures were extremely high. On the drier soil the shearing strength shows a significant increase with the normal load, and the theoretical pore pressures were low. From this it may be reasoned that in the soil where the pore pressures were low, the normal load was effectively transmitted to the soil grains and, consequently, the shearing strength increased as the normal load was increased. On the other hand, the wet soil theoretically had high pore pressures which neutralized or partially neutralized the applied normal loads and thereby resulted in low shearing strength.

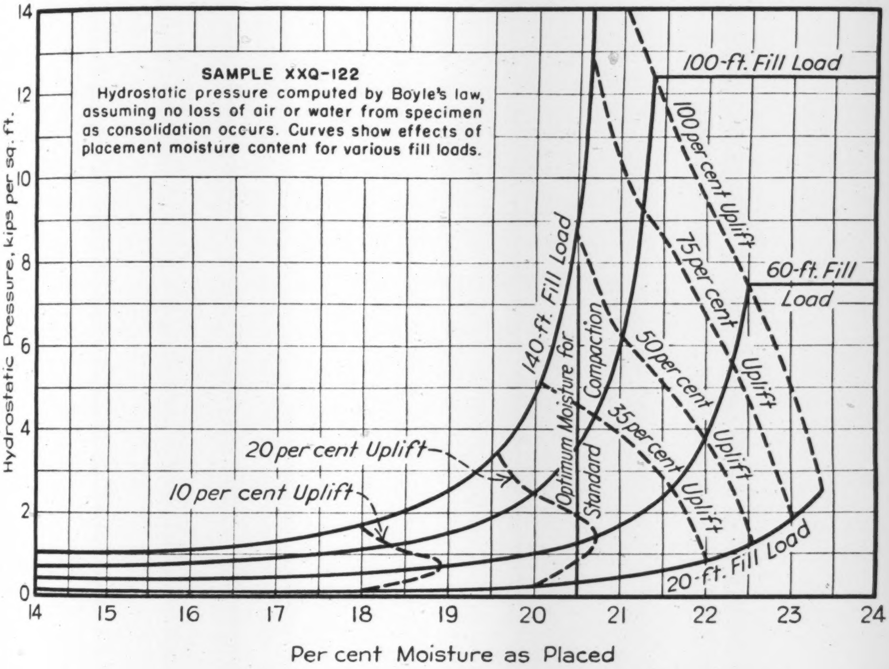


FIG. 4.—Computed Internal Pressure and Data for Internal Pressure Studies.

In a third series of tests, an investigation on the shearing strength of soils was made to show the effects of preconsolidation time and the rate of applying the shearing loads. These investigations were made on a very fine silty clay which had a particle size about 77 per cent, by weight, smaller than five μ, as determined by the hydrometer analysis. The results of these investigations are summarized in Fig. 5. The thickness of all specimens was 1 in. and free drainage was permitted at the top and the bottom of the specimen. An inspection of Fig. 5 will show that almost any strength can be obtained, depending upon how the soil is preconsolidated and how rapidly it is stressed in shear. These curves, it is believed, merely show that the results are greatly affected by the time allowed for pore-pressure dissipation and that both the preconsolidation time and the shearing rate must be controlled to reduce the pore pressure effectively.

ATTEMPTED MEASUREMENTS OF THE PORE PRESSURES

Pore pressures may be divided into three types: namely, induced pore pressure resulting from compression of a compressible fluid in the soil pores, transient percolation pressures which are the result of a lag in the flow of percolating water, and percolation pressures for a steady state of flow. The induced pore pressures are specifically related to the shear tests and are of primary interest, and it has been along this line that most of the measurements in the Bureau of Reclamation studies have been concerned.

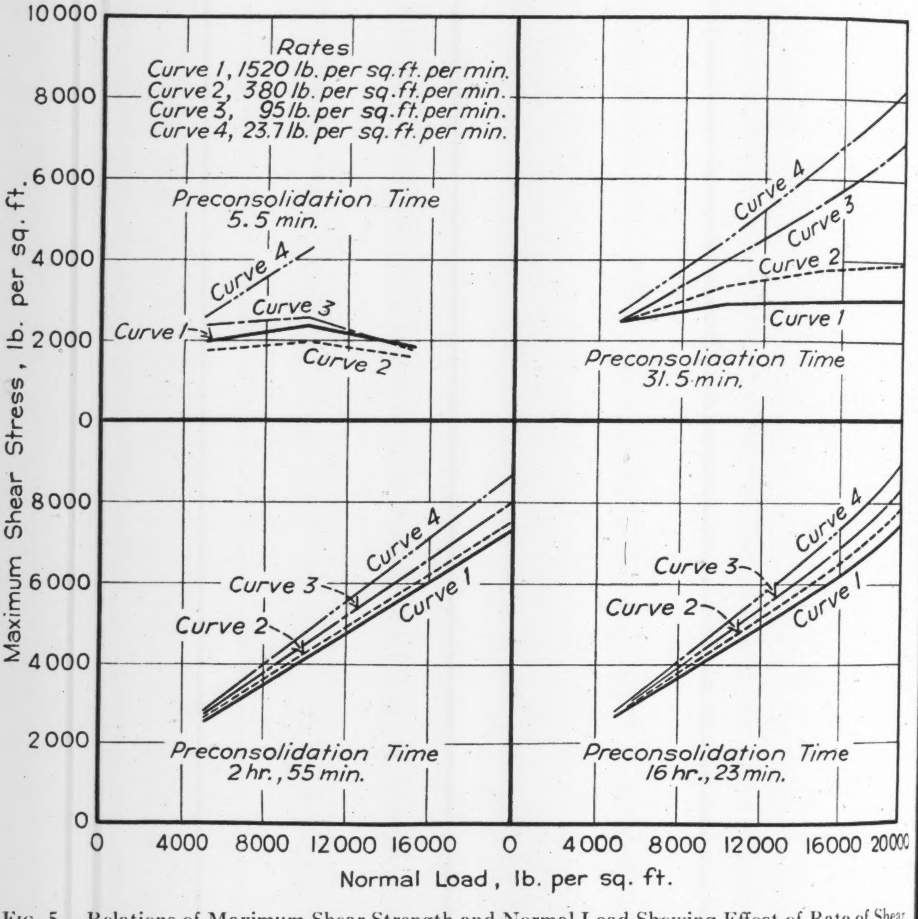


FIG. 5.—Relations of Maximum Shear Strength and Normal Load Showing Effect of Rate of Shear.

Even before measurements were started, it was realized that the measuring device would have to measure pressure without any flow from the soil mass if the pressures were to be exact. The device used requires a very small flow; therefore it was known that the pressure could be in error. A very small flow from a point in a soil mass will dis-

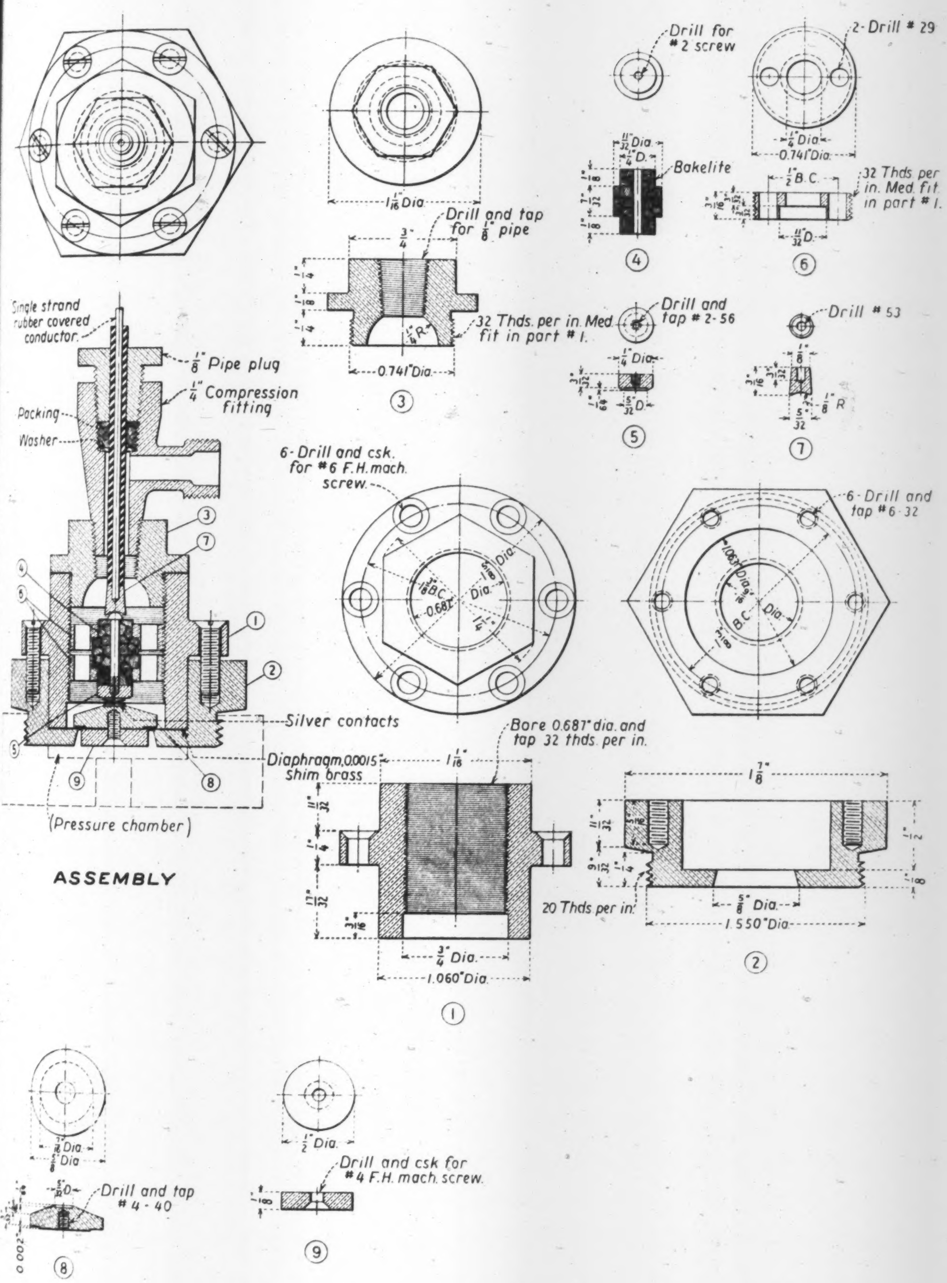

Drill for #2 screw
2-Drill #29
$1\frac{1}{16}$" Dia.
$\frac{11}{32}$" Dia.
$\frac{1}{4}$" D.
Bakelite
$\frac{1}{4}$" Dia.
0.741" Dia.
$\frac{1}{2}$" B.C.
32 Thds per in. Med. fit in part #1.
$\frac{11}{32}$" D.
Drill and tap for $\frac{1}{8}$" pipe
$\frac{3}{4}$"
$\frac{1}{4}$" R
32 Thds. per in. Med. fit in part #1.
0.741" Dia.
Drill and tap #2-56
$\frac{1}{4}$" Dia.
$\frac{5}{32}$" D.
Drill #53
$\frac{1}{8}$" R
Single strand rubber covered conductor
$\frac{1}{8}$" Pipe plug
$\frac{1}{4}$" Compression fitting
Packing
Washer
6-Drill and csk. for #6 F.H. mach. screw.
6-Drill and tap #6-32
B.C.
0.687
Dia.
1.063" Dia.
Silver contacts
Bore 0.681" dia. and tap 32 thds. per in.
Diaphragm, 0.0015 shim brass
$1\frac{1}{16}$"
$1\frac{7}{8}$"
(Pressure chamber)
ASSEMBLY
20 Thds per in.
$\frac{5}{8}$" Dia.
1.550" Dia.
$\frac{3}{4}$" Dia.
1.060" Dia.
$\frac{7}{16}$" Dia.
$\frac{5}{8}$" Dia
Drill and tap #4-40
0.002
$\frac{1}{2}$" Dia.
Drill and csk for #4 F.H. mach. screw.
①
②
③
④
⑤
⑥
⑦
⑧
⑨

FIG. 6.—Pressure Cell.

turb the equilibrium around it and thus the measured pressure is likely to be a function of the ability of the surrounding soil to give up enough water to supply the demand of the measuring apparatus. For this case, the measured pressures should be less than the true pressures. On the other hand, if the measuring device actually forces water into the soil mass, it will tend to make the measured pressure at this point greater than those that would prevail without disturbance.

The apparatus used could work in both the above-mentioned ways as the pressure is indicated by the deflection of a flexible diaphragm which makes and breaks contact with a fixed contact point. The making and breaking of the contact is registered electrically by the use of an ammeter. The diaphragm is deflected by inserting air pressure on the contact side. The air pressure just necessary to break the contact is measured and is considered equal to the hydrostatic pressure on the opposite (pressure) side of the diaphragm. For the apparatus in use, a pressure differential of only $\frac{1}{4}$ in. of water is necessary to break the contact. If this apparatus is handled carefully, the amount of deflection of the diaphragm is extremely small.

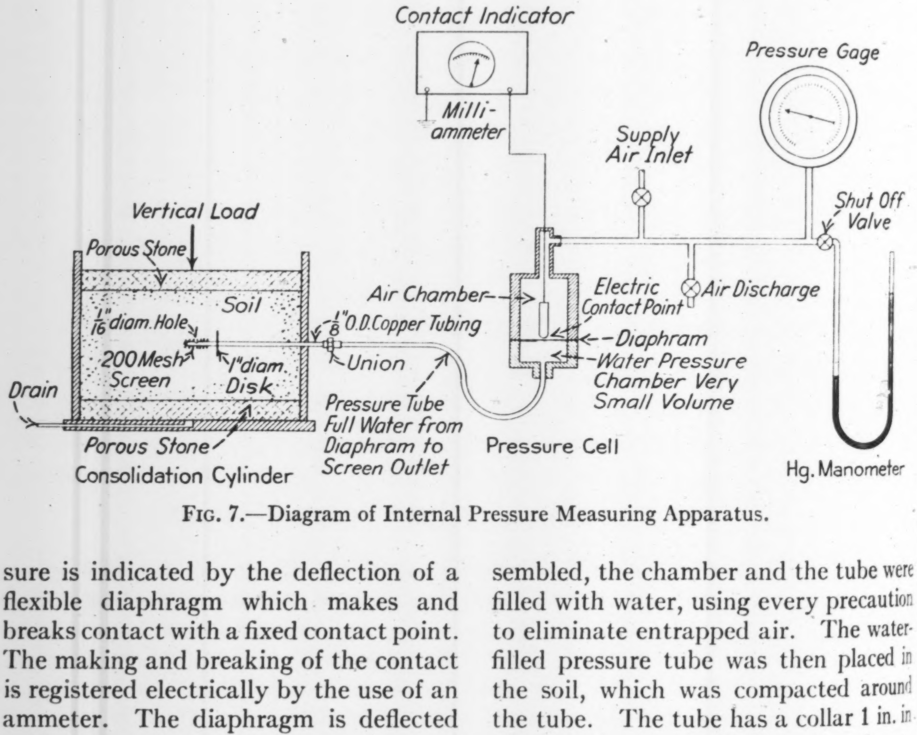
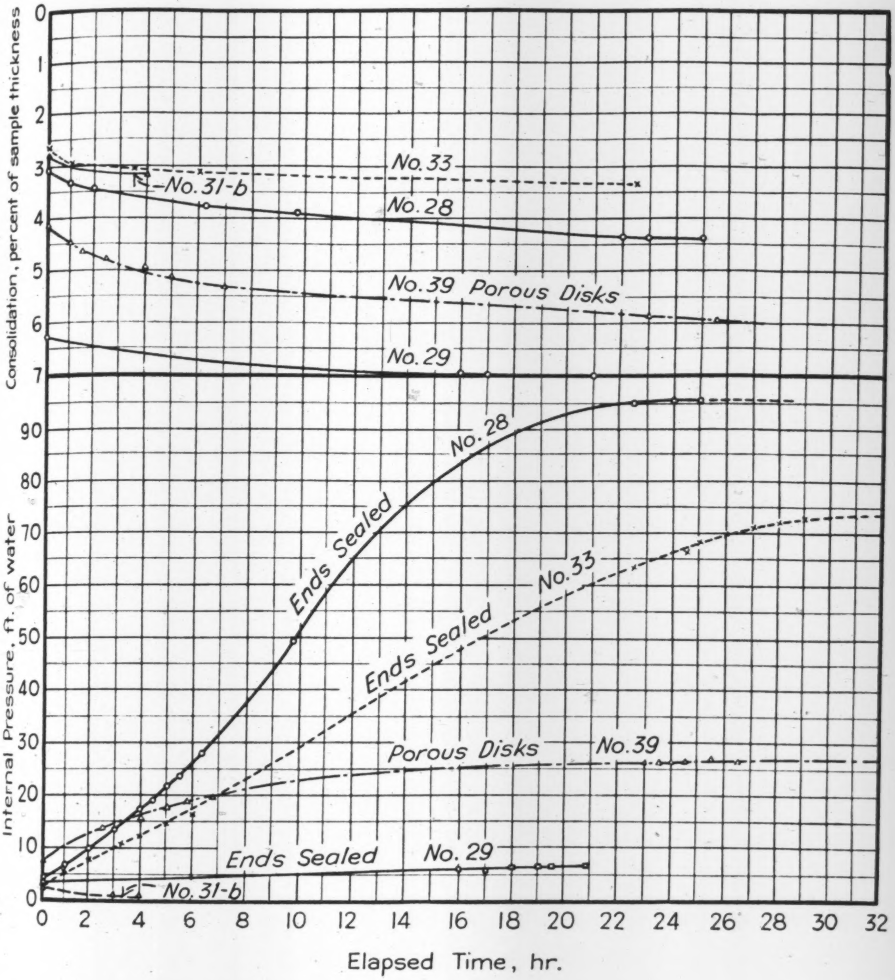

Contact Indicator
Milli-ammeter
Pressure Gage
Supply Air Inlet
Shut Off Valve
Vertical Load
Porous Stone
Soil
$\frac{1}{16}$" diam. Hole
200 Mesh Screen
1" diam. Disk
Drain
Porous Stone
Consolidation Cylinder
Air Chamber
$\frac{1}{8}$" O.D. Copper Tubing
Union
Pressure Tube Full Water from Diaphram to Screen Outlet
Electric Contact Point
Air Discharge
Diaphram
Water Pressure Chamber Very Small Volume
Pressure Cell
Hg. Manometer

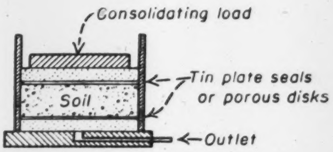
FIG. 7.—Diagram of Internal Pressure Measuring Apparatus.

The pressure-measuring device which is shown in detail in Fig. 6 is a modification of the Goldbeck cell. On the pressure side of the diaphragm a $\frac{1}{8}$-in. outside-diameter copper tube with a $\frac{1}{16}$-in. bore has been connected so as to form a sealed chamber covering the pressure face of the diaphragm. The end of the copper tube was perforated and the perforations covered with a very fine screen. When the tube and the cell were assembled, the chamber and the tube were filled with water, using every precaution to eliminate entrapped air. The water-filled pressure tube was then placed in the soil, which was compacted around the tube. The tube has a collar 1 in. in diameter just back of the perforations to prevent leakage along the walls of the tube. Figure 7 shows how the apparatus was set up.

The soils were compacted to a thickness of 3 in. in a container 8 in. in diameter. The pressure tube was set so that the openings would be at the center of



TEST	PLACEMENT		PERCENTAGE OF PLACEMENT VOLUME		
	MOISTURE, PER CENT DRY WT.	DENSITY, LB. PER CU. FT.	AIR	SOIL	WATER
No. 31-b	18.6	100.0	11.2	59.0	29.8
No. 29	21.3	100.4	6.5	59.2	34.3
No. 33	22.6	100.7	4.1	59.4	36.5
No. 28	24.2	89.1	3.9	52.5	43.6
*No 39	23.6	101.0	2.2	59.6	38.2



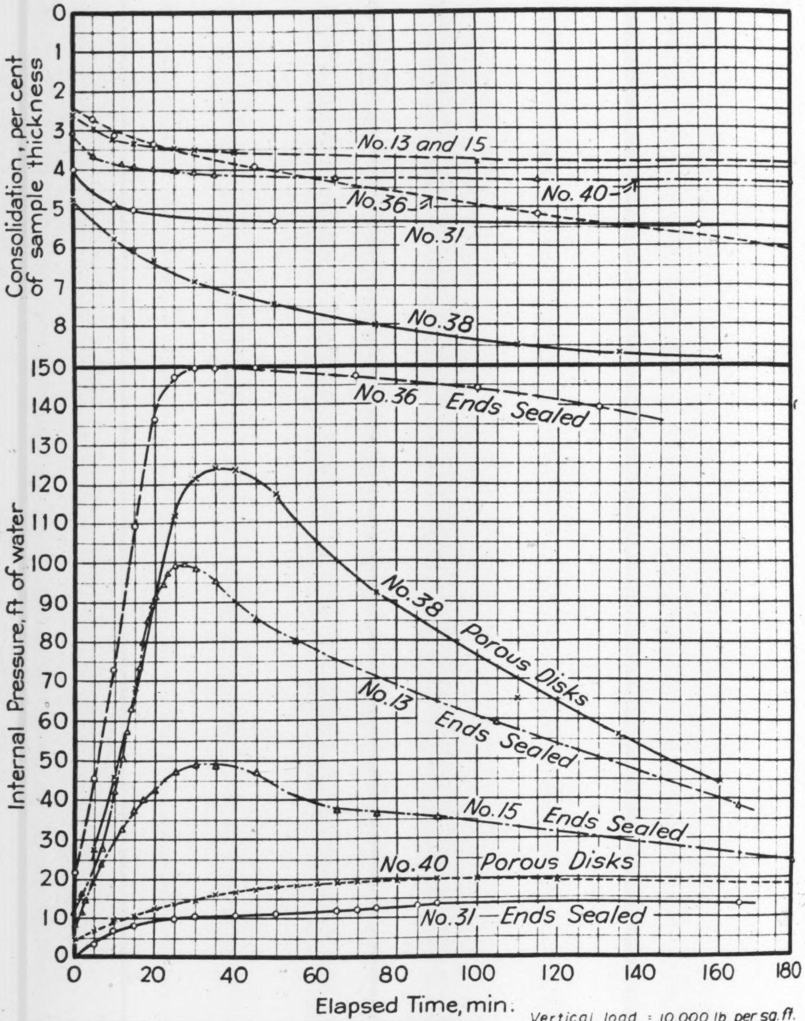
SKETCH OF CONSOLIDATING APPARATUS

*All tests run with tin plate seal at top and bottom of sample except No. 39 where drainage was allowed by porous disks.

Vertical load = 10,000 lb. per sq. ft.
= 160 ft. of water

Depth sample = 3-in.
Area sample = 0.3494 sq. ft.
Laboratory soil sample No. XHH-98

FIG. 8.—Effect of Placement Moisture on Internal Pressure for a Fine Clay.

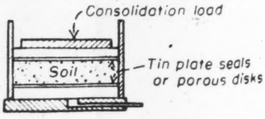


TEST	PLACEMENT		PERCENTAGE OF PLACEMENT VOLUME		
	MOISTURE PER CENT DRY WT.	DENSITY LB. PER CU. FT.	AIR	SOIL	WATER
NO. 36	17.5	111.4	2.4	66.4	31.2
NO. 38*	16.8	114.0	1.3	68.0	30.7
NO. 13	15.3	114.1	3.8	68.0	28.2
NO. 15	15.0	114.1	4.9	67.7	27.4
NO. 40	14.8	114.2	5.0	68.0	27.0
NO. 31	14.6	114.2	5.2	68.1	26.7

* All tests run with partial seal at top and bottom of sample except No 38 and 40 where drainage was allowed with porous disks.

Vertical load = 10,000 lb per sq. ft.
= 160 ft of water

Depth sample = 3-in.
Area sample = 0.3494 sq. ft.
Laboratory soil sample No. XJ-162



SKETCH OF CONSOLIDATING APPARATUS

FIG. 9.—Effect of Placement Moisture on Internal Pressure for a Loam.

the specimen as to depth and area. The sample thus prepared was consolidated with a load of 10,000 lb. per sq. ft. (equivalent to 160 ft. of water pressure) and both the pore pressure and time-consolidation measurements were taken. The results of several tests on a tough colloidal clay are shown in Fig. 8. The mechanical analysis of this soil shows about 55 per cent smaller than 5 μ and 96 per cent passing the No. 200 sieve. The results of several tests on a loam soil are shown in Fig. 9. The mechanical analysis of this soil shows about 13 per cent smaller than 5 μ and 62 per cent passing the No. 200 sieve.

At first the results obtained on the clay were discouraging as they did not appear to fit the concept very well. The time necessary to create the maximum pore pressure seemed to be far too long. However, if the clay surrounding the measuring point did not give up sufficient water to supply the demand of the pressure indicator, some time would be required to supply this demand. This reasoning may explain the apparent lag in the pressure formation.

Tests of a similar nature on a loam soil were more gratifying in that the measured pore pressures behaved more along expected lines. Under different test conditions the measured pore pressures ranged from about 9 to 93 per cent of the applied consolidating load. Whether or not the measured pressures were identical to the true pore pressures is of small importance if proof of the theory of pore-pressure formation is all that is desired. On the other hand, if physical laws are to be formulated from such tests, the data are inadequate. It is very probable that the pressure tube did extract a small quantity of water from the immediate vicinity of the measuring points and thus the measured pressures should be less than the actual pore pressures without any disturbance. Notice that on Figs. 8 and 9 certain curves are marked "porous disks" and others "ends sealed." The data for the curves marked "porous disks" were determined by using porous stones at both ends of the specimen, which allowed free drainage. The other tests marked "ends sealed" were made by placing a thin, impervious disk between the porous stones and the soil surfaces. These disks were about $\frac{1}{8}$ in. smaller in diameter than the metal cylinder; therefore drainage was permitted on the circumferential edges of the top and the bottom of the specimen.

The above-described tests were intended to give basic data upon which the amount of pore pressure could be estimated. They also were intended to give a measure of the rate of dissipation of pore pressure. Actually, the results were not adequate because there were too many uncontrolled variables. However, they do show that pore pressure is present, may be of considerable magnitude, and may dissipate very slowly. The tests were a partial substantiation of the concept of pore pressure and were of some value because trends observed were believed to be in the right direction. Furthermore, they lead to another method of approach to the problem, which will be described later.

In addition to studying the nature of induced pore pressures, a small amount of work has been done on the dissipation rate of transient percolation pore pressures. The specimen was compacted in the 8-in. diameter percolation cylinder in the same manner as for a standard percolation test. The sample had a compacted thickness of 3 in., with a 1-in. porous stone at the top and bottom. The bottom porous stone and immediate chamber was carefully filled with water to eliminate all entrapped air in so far as practical. On one side of this bottom chamber a connection was made to a standpipe or water supply, and at the bottom of the chamber one of the modified Goldbeck cells was inserted so that the pressure of the water in this chamber could be determined. The standpipe was filled with water and a standard percolation test run. After the water flowed through the specimen for several days and the amount of flow became constant, the incoming water supply was shut off and the time-pressure readings in the bottom water chamber were continued. The results of one such test are plotted in Fig. 10.

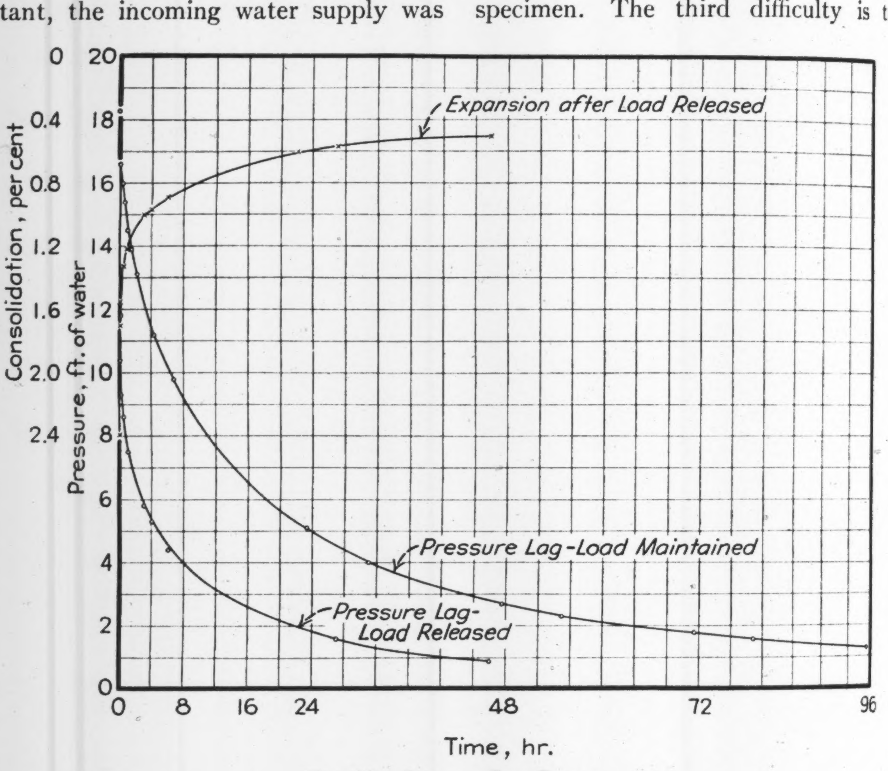


FIG. 10.—Pressure Lag Curves.

From Fig. 10 it may be noted that the lag in pressure is significant. After 4 hr., about 70 per cent of the original pressure remained, and at the end of 24 hr., about one-third of the original pressure remained even though the dissipation distance was only 3 in.

As previously stated, there are many difficulties involved in making measurements of pore pressure. The first difficulty is to develop a pressure indicator that requires no flow or to develop a test procedure that will properly evaluate the results even though small flow does occur. The second difficulty is to measure or control the fluid outflow from the specimen. The third difficulty is to develop measuring equipment as well as test procedure that will accurately determine the volume of solids, water, air, volume of the total specimen, and volume change of the specimen under load.

TRIAXIAL SHEAR MACHINE

The triaxial shear machine can be so designed and operated that the measurement of many of the previously mentioned variables can be eliminated or at least controlled with a fair degree of accuracy. The volume change of the specimen under different loading conditions may be observed. The applied loads can be measured and maintained constant at any desired condition. The loading can be applied in increments, at a constant rate of stress change, or at a constant rate of strain. The stress system produced is one which may be analyzed by known principles of applied mechanics. The drainage of the specimen may be accurately controlled, or the specimen may be absolutely sealed, which eliminates the variable of drainage and thus affords a type of approach which the author believes will be of considerable influence on the solution of the problem of shear. The idea proposed is to limit or control drainage so that the pore pressures can be determined and corrections made for the induced pore pressures.

The sealed specimen affords an opportunity to use the previously described pressure tube and apparatus with a satisfactory degree of accuracy, because the extraction of a small quantity of water from a large soil mass will not alter the pressure condition of the whole mass even though it may greatly change the pressure conditions at a point. Accurate pressure measurements may be obtained by holding the applied stress condition constant for a sufficient length of time to allow the small disturbance created at the measuring point to become neutralized. To insure that the pressure is equalized, the measurements should be continued until they show that constant pressure prevails. Such tests can be repeated at different stresses or volume change conditions until a relation is established between the volume change and the induced pore pressure. Then if the volume change is measured on the sealed triaxial specimen, the pore-pressure correction may be evaluated. Considerable theoretical speculation has been made regarding a method to compute the induced pore pressures for these sealed specimens. The first consideration was, as previously stated, that the entrapped air in the soil mass behaves according to Boyle's law for compressibility of gases. The formula may be written as follows:

$$P_o Va_o = P' Va_c \quad \ldots\ldots\ldots (1)$$

where:

P_o = initial pore pressure, absolute,
P' = pore pressure (absolute), after volume change, c,
Va_o = initial air volume at P_o pressure, and
Va_c = compressed volume of air = $(Va_o - c)$.

Rewriting Eq. 1 or:

$$P' = P_o\left(\frac{Va_o}{Va_c}\right) \quad \ldots\ldots\ldots (2)$$

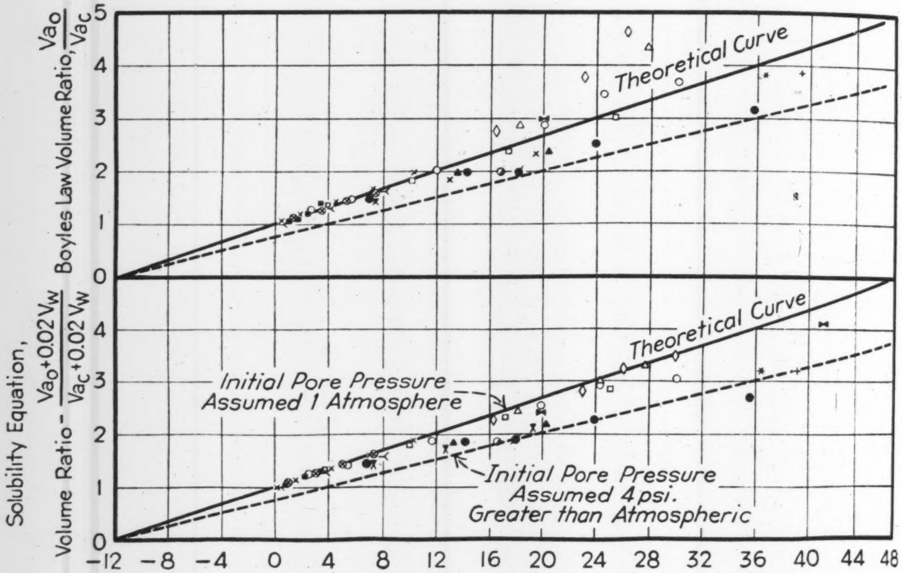
Now, if the external pressure P_A is atmospheric, the effective internal or pore pressure should be reduced by P_A. Then Eq. 2 becomes

$$P_e = P' - P_A = P_o\left(\frac{Va_o}{Va_c}\right) - P_A \quad . (3)$$

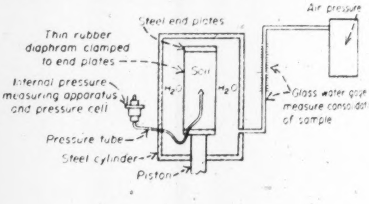
where P_e equals effective pore pressure. Now, if the initial pore pressure P_o is equal to P_A, Eq. 3 becomes

$$P_e = P_A\left(\frac{Va_o}{Va_c} - 1\right) \quad \ldots\ldots (4)$$

The weight of the gas undergoing compression must be a constant if Boyle's law is applied. The weight of the gas molecules in a sealed specimen does remain constant; however, it is well known that water will dissolve air and that the amount of air dissolved is a function of the pressure. Therefore, there is some question as to whether the weight of the gas undergoing compression will remain constant. Regarding the ability of water to dissolve air, the following statements are taken from A. H. Gibson's "Hydraulics and Its Applications"[4]: "At ordinary temperatures and pressures, water is capable of dissolving about 2 per cent of its own volume of air.... At a given temperature, the volume of gas absorbed is sensibly independent of the pressure, so that the weight absorbed is proportional to the pressure." From these statements we conclude that the weight of free air in a specimen does not



	NUMBER OF POINTS	TEST No.	DRY DENSITY LB. PER CU. FT.	MOISTURE PERCENT DRY WT.	PERCENTAGE OF ORIGINAL VOLUME		
					AIR	WATER	SOIL
●	4	58	126.8	9.72	4.40	19.8	75.8
+	1	59	125.7	9.84	4.97	19.9	75.2
•	1	60	126.0	9.74	4.95	19.7	75.3
▲	2	61	126.1	9.83	4.69	19.9	75.5
⁄	1	62	126.2	9.80	4.72	19.9	75.3
◑	1	64	125.9	9.79	4.90	19.8	75.3
△	3	65	126.6	10.04	3.91	20.4	75.7
□	4	91	114.6	11.02	11.20	20.2	68.5
⧓	2	93	124.8	11.10	3.10	22.2	74.7
◇	4	109	124.4	11.19	3.26	22.4	74.4
■	4	110	119.1	7.85	13.83	15.0	71.2
●	4	111	109.1	7.42	21.80	13.0	65.2
×	5	112	121.0	9.92	8.41	19.3	72.4
<	3	113	125.4	9.86	5.17	19.8	75.0
⧗	3	116	125.9	9.91	4.67	20.0	75.3
○	6	118	124.2	10.48	4.72	20.9	75.3


Air pressure
Steel end plates
Thin rubber diaphram clamped to end plates
Soil
H_2O
H_2O
Internal pressure measuring apparatus and pressure cell
Glass water gage to measure consolidation of sample
Pressure tube
Steel cylinder
Piston

BOYLE'S LAW:

$$P_e = P_O\left(\frac{V_{a_O}}{V_{a_C}}\right) - P_A$$

Where P_e = Effective internal pressure
V_{a_O} = Initial air volume
V_{a_C} = Compressed air volume
P_A = Atmospheric pressure, (absolute)
P_O = Initial pore pressure, (absolute)

BOYLE'S LAW MODIFIED TO INCLUDE THE EFFECT OF AIR SOLUBILITY IN THE WATER:

Solubility equation, $P_e = P_O\left(\frac{V_{a_O}+bV_w}{V_{a_C}+bV_w}\right) - P_A$

Where V_w = Water volume present to dissolve air
b = Capacity of water to dissolve air, (assumed 2% of the water volume)

FIG. 11.—Internal Hydrostatic Pressure Measurements Compared with Theoretical Considerations.

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[4] Fourth edition, the Whitefriars Press, Ltd., London, England (1930).

remain constant with compression or increased pressure in the entrapped air. But since the weight of gas going into solution is directly proportional to the pressure, we may apply Boyle's law if we include the weight of the gas dissolved in the water along with the weight of gas entrapped in the specimen. Now let us assume that the value of Va_o includes only the entrapped or free air in the specimen. Then the actual air volume will be,

$$Va_o + bV_w \quad \dots\dots\dots\dots (5)$$

where:

b = capacity of the water to dissolve air, and

V_w = volume of water available to dissolve the air.

Now replace Va_o by $Va_o + bV_w$ in Eqs. 3 and 4 and we obtain

$$P_e = P_o\left(\frac{Va_o + bV_w}{Va_c + bV_w}\right) - P_A \quad \dots (6)$$

$$P_e = P_A\left(\frac{Va_o + bV_w}{Va_c + bV_w} - 1\right) \quad \dots (7)$$

In this connection it should be pointed out that the only fundamental difference between Eqs. 3 and 6, and 4 and 7 is in the computation of the initial air volume. The second consideration is necessary to explain why Boyle's law presumably can be applied even though a part of the entrapped air may be driven into the water.

The above speculation must, of course, be substantiated by actual observations, and several observations have been made which are somewhat gratifying, although they are far from adequate for positive proof of the speculation. Figure 11 shows the results from some 17 different tests on one soil, for which pore pressures were determined for several different volume change conditions, giving a total of 47 test points. The measured pressures are plotted in relation to both the speculations discussed above. It is obvious that the speculation which includes the effect of air solubility in water more nearly agrees with the measured pressures. It is also obvious from this figure that the test data are far too widely dispersed for a definite conclusion to be drawn. In addition to the limited degree of accuracy possible for the measurement of the original air volume, water volume, and the consolidation of the entire specimen, there is also the possibility that the initial pressure of the entrapped air was greater than atmospheric, and therefore the induced pressures should be increased as indicated by Eq. 3 or Eq. 6. The effect of the initial pressure of the entrapped air is shown in Fig. 11. For example, the initial effective pressure was assumed as 4 psi. and the theoretical pressures were computed and plotted as a dotted line. A second possible reason for the increase in the induced (or measured) pressure is that sufficient time may not have been allowed for the air to dissolve in the water; thus the pressure could be practically any value between those shown by Eqs. 3 and 6. This range of difference may be large or small, depending upon the ratio of air and water in the sealed container. To show the effects of different air and water ratios and also the effect of the water dissolving a part of the entrapped air as the pressure is increased, the solutions of Eqs. 3 and 6 are summarized graphically in Fig. 12. In this figure, the effective internal pressure is plotted against the ratio of the original entrapped air volume to the compressed air volume. From this figure it is obvious that the capacity of the water to dissolve air, as well as its efficiency in dissolving the air, is an important function of the induced pressure. In view of the many sources of error possible, these tests, in the author's opinion, give a fair substantiation to the concept that the pore pressure may be evaluated by computations. However, much more work will be required to study possible sources of error.

The above-described tests were all made with the triaxial shear machine without applying any compressive load other than the water pressure in the pressure chamber. At the present time a simpler device is being planned which will be simply a sealed chamber with a volume change gage attached. The triaxial shear machine can then be released for shear testing only.

The results of triaxial shear tests made on sealed specimens have been corrected by deducting the computed pore pressure from both the major and minor principal stresses. The pore pressure was computed from the initial and compressed air volume using the method indicated by Eq. 4. These corrected results appear quite favorable in that the same material, placed at widely different

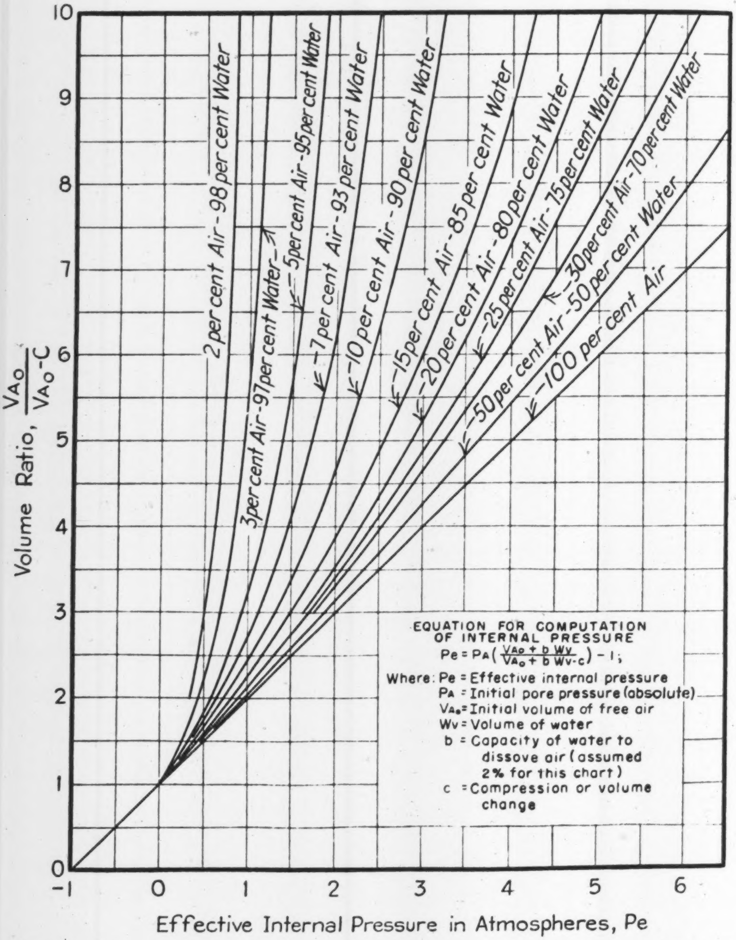
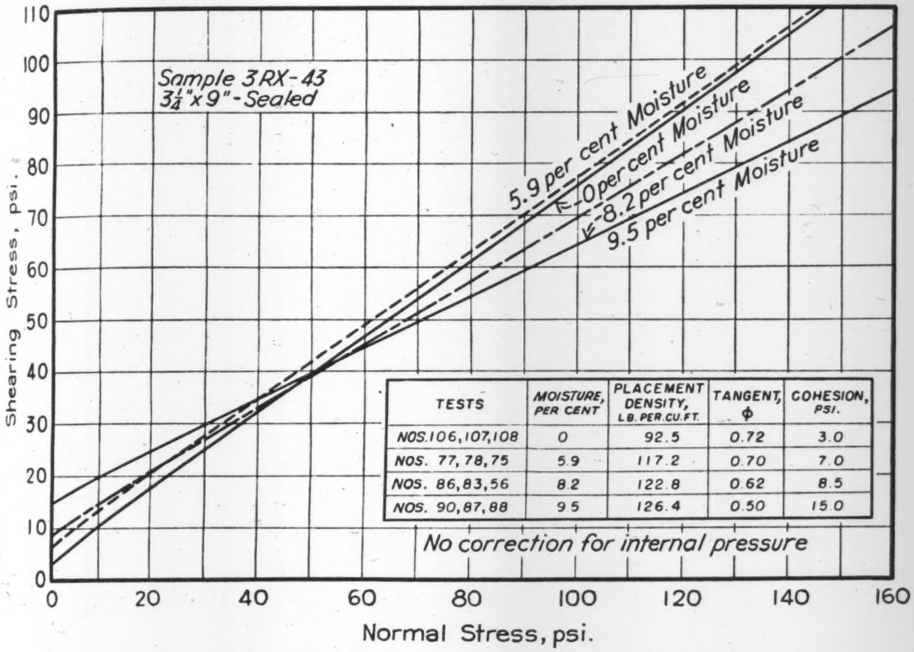


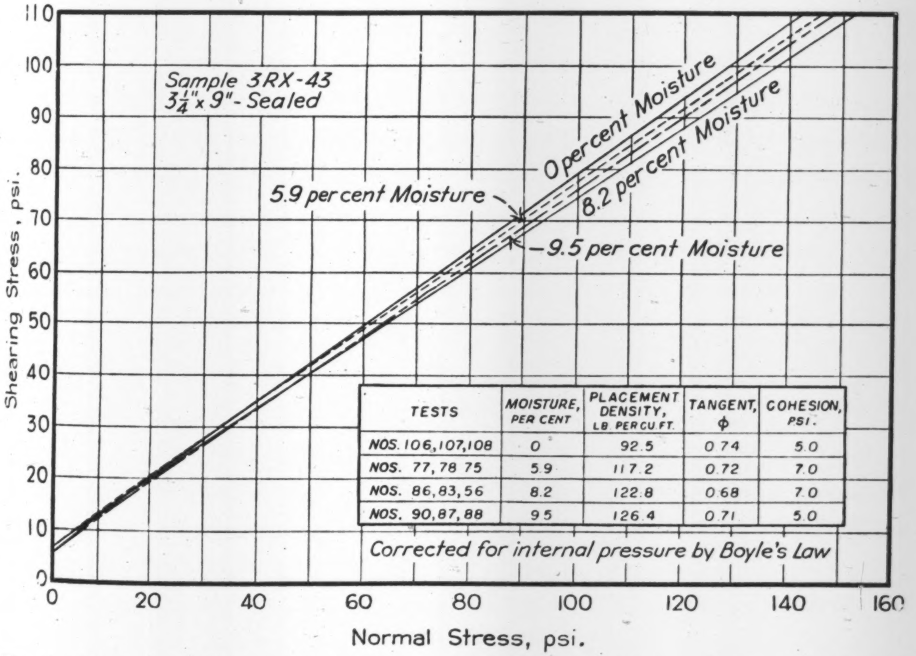
FIG. 12.—Theoretical Considerations Showing the Effect of Air Solubility in Water on the Internal Pressure.



TESTS	MOISTURE, PER CENT	PLACEMENT DENSITY, LB. PER CU. FT.	TANGENT, Φ	COHESION, PSI.
NOS. 106, 107, 108	0	92.5	0.72	3.0
NOS. 77, 78, 75	5.9	117.2	0.70	7.0
NOS. 86, 83, 56	8.2	122.8	0.62	8.5
NOS. 90, 87, 88	9.5	126.4	0.50	15.0

No correction for internal pressure

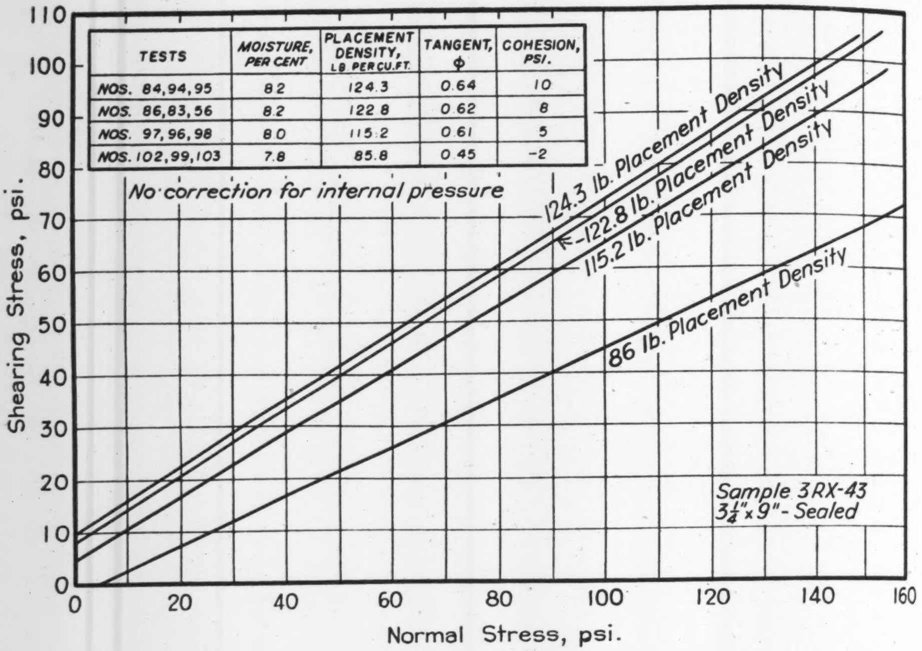
FIG. 13.—Summary of Limiting Shearing Strength for Various Initial Moisture Contents.



TESTS	MOISTURE, PER CENT	PLACEMENT DENSITY, LB. PER CU. FT.	TANGENT, Φ	COHESION, PSI.
NOS. 106, 107, 108	0	92.5	0.74	5.0
NOS. 77, 78 75	5.9	117.2	0.72	7.0
NOS. 86, 83, 56	8.2	122.8	0.68	7.0
NOS. 90, 87, 88	9.5	126.4	0.71	5.0

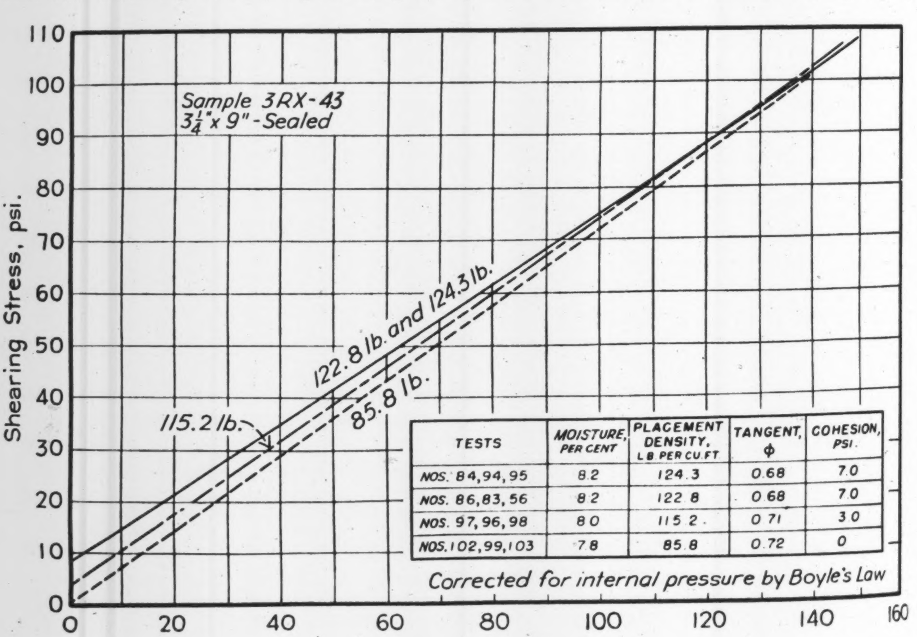
Corrected for internal pressure by Boyle's Law

FIG. 14.—Summary of Limiting Shearing Strength for Various Moisture, Corrected for Internal Pressures.



TESTS	MOISTURE, PER CENT	PLACEMENT DENSITY, LB PER CU. FT.	TANGENT, φ	COHESION, PSI.
NOS. 84,94,95	8.2	124.3	0.64	10
NOS. 86,83,56	8.2	122.8	0.62	8
NOS. 97,96,98	8.0	115.2	0.61	5
NOS. 102,99,103	7.8	85.8	0.45	-2

FIG. 15.—Summary of Limiting Shearing Strength for Constant Moisture and Varying Density.



TESTS	MOISTURE, PER CENT	PLACEMENT DENSITY, LB PER CU. FT	TANGENT, φ	COHESION, PSI.
NOS. 84,94,95	8.2	124.3	0.68	7.0
NOS. 86,83,56	8.2	122.8	0.68	7.0
NOS. 97,96,98	8.0	115.2	0.71	3.0
NOS. 102,99,103	7.8	85.8	0.72	0

FIG. 16.—Summary of Limiting Shearing Strength for Constant Moisture and Varying Density, Corrected for Internal Pressure.

densities and moistures, give practically the same coefficient of friction regardless of the placement density or moisture. On the other hand, the uncorrected results take on the appearance of those that may be obtained with the direct shear machine when soils are tested at different densities, moistures, and rates of loading. Figure 13 shows the uncorrected limiting shear curves as determined by the envelope of the Mohr's stress circles for a series of tests made at different densities and moistures. Each of the curves was determined by at least three tests. Figure 14 shows the same data corrected for the computed pore pressures. The tan ϕ for the uncorrected data varies from 0.50 up to 0.72, while the corrected tan ϕ varies from 0.68 up to 0.74. Figure 15 shows the uncorrected data for a series of tests on the same soil for which the moisture content by dry weight of soil was held constant and the density varied from as low as 85 lb. per cu. ft. up to 124 lb. per cu. ft. Figure 16 shows this same data corrected by the computed pore pressure. The tan ϕ for the uncorrected data varies from 0.45 up to 0.64, while the corrected tan ϕ varies from 0.68 to 0.72. These tests were made on a slightly cohesive sandy loam that had about 14 per cent, by weight, smaller than 5 μ. The direct shear test on the same material, using a free-draining sample of 1 in. thickness, gave an indicated tan ϕ of 0.71. These results, in the author's opinion, give a substantiation of the concept of pore-pressure effects, as well as a gratifying degree of substantiation to the speculation that pore pressure can be evaluated for the sealed specimens.

Whether this procedure can be carried forward to include real clays or materials of extremely low permeability is a question which is worthy of concentrated research. The soil used in the investigation on the sealed specimens described in this report was relatively permeable and should have transmitted pressure rather rapidly; therefore, it is believed that the possibility of concentrations of higher pore pressures along the zones of highest shearing stress did not occur. On the other hand, possible concentration of pore pressures will undoubtedly be a serious problem for clays. Such specimens may have to be stressed in shear very slowly to allow distribution of the possible concentrations of pore pressure.

For the purpose of further discussion, let it be assumed that the limiting coefficient of friction for a soil without pore pressure is known and that it is constant regardless of density and moisture conditions. Even with these assumptions, the problem of stability could be only partially solved because the pore pressure present may reduce the contact pressures to such an extent that the shearing strength could be practically any value between zero and the upper limiting value. In view of the partial substantiation of the speculation that the induced pore pressures can be computed, let us further assume that we do know the limiting value of the pore pressure. The problem is still far from an ultimate solution as far as the actual design of a structure is concerned, because during construction there will undoubtedly be some dissipation of the induced pore pressures. The problem of determining coefficients of pore-pressure dissipation is, in the author's opinion, one of the most difficult of all. It may be that the much-used time-consolidation test can be combined with a measured time rate of drainage of both water and air for a solution of the problem. The time-consolidation test alone is at least a good indicator of this property.

In lieu of being able to predict the pore pressure under actual construction conditions, hydrostatic pressure indicators may be installed at numerous points in the structure which can be read as construction or external stress conditions change. From these readings, dangerous conditions may be predicted and corrective measures applied. The Bureau of Reclamation has for some time installed hydrostatic-pressure indicators in the completed earth dams and has recently started to install hydrostatic-pressure indicators in the embankment and foundation of earth dams as they are constructed.

CONCLUSIONS

The shearing strength of a soil involves at least three fundamental factors: namely, the frictional resistance produced by contact pressure between the soil grains, the effective pore pressure present to neutralize a part of the external load, and the capacity of the soil to eliminate the pore pressure. There may be other items, such as moisture films, chemical composition, etc., to be considered, but a complete understanding of the pore pressure and its effects will go a long way toward clarification of the problem of shear. A study of these fundamentals is very difficult and may require years of development, but, in view of the ultimate achievement, it is believed well worth while.

Definite conclusions cannot be drawn from the meager data described in this report, but the data have been interpreted as being sufficiently favorable to formulate the following opinions:

1. The induced pore pressures may be predicted if sealed specimens are tested and sufficient care is used in determining the original volume of the specimen, the change in volume with applied loading, and the original soil, air, and water volumes.

2. The triaxial shear test results may be corrected for the induced pore pressures and the limiting shearing strength without pore pressure predicted.

3. The limiting shearing strength may be realized only in part under actual conditions in the structure, depending upon the consolidation or limiting induced pore pressures, the capacity of the soil to dissipate these pore pressures, the rate of loading, the distance through which dissipation must occur, etc. Likewise, variations in test procedure on materials of low permeability for specimens that are permitted to drain may give widely different shearing strengths. The shearing strength determined by tests that are subjected to the distortions of loading and drainage as compared to the actual structure may give results that are far misplaced from the strength of a soil in the structure. The real problem in a shear test is the procedure of controlling the test so that the specimen can be completely analyzed and the data evaluated.

4. The idea of a compressible fluid (mixture of water and air) in the soil pores is a pertinent part of the concept of pore pressure because the amount of drainage necessary to dissipate the pore pressure may be considerable. It is the author's contention as well as experience that a compacted soil specimen cannot be completely saturated by any reasonable procedure. It is also the author's experience that even undisturbed samples taken below ground water level contain air.

5. The nature of the soil to consolidate as it is loaded is an important function of its stability, especially if the permeability is low, because consolidation tends to produce pore pressures. A soil that consolidates slowly does so principally because the induced pressures dissipate slowly; thus, such materials are generally of low stability because of excess pore pressure. Materials that are preconsolidated before loading to such an extent that the loading produces little or no volume change are, in general, stable because the small volume change

induces small pore pressures. On the other hand, very permeable soils may consolidate a large amount and remain stable at all times because the pore pressures are rapidly dissipated. Thus the loading is transmitted as contact pressure throughout the soil structure.

6. Before the above opinions can be substantiated and applied on a scientific basis, considerable research will be necessary.

All activities of the Bureau of Reclamation are supervised by John C. Page, Commissioner, Washington, D. C., and all engineering and construction is under the direction of R. F. Walter, Chief Engineer and S. O. Harper, Assistant Chief Engineer, with headquarters in Denver, Colo. Research and design work is directed by J. L. Savage, Chief Designing Engineer and W. H. Nalder, Assistant Designing Engineer. Arthur Ruettgers and R. F. Blanks, head the Materials Testing and Control Division of the Denver organization with the author in charge of the earth materials laboratory.

Acknowledgment:

The author wishes to acknowledge that the original idea of the effects of entrapped air on internal pressure and its consequent effects on stability were instigated by J. H. A. Brahtz. Others concurring with Brahtz and cooperating in this type of investigation include F. F. Smith, engineer in charge of the design of earth dams, D. R. May, and J. A. Haine, also of the earth-dam design section. The constructive criticism, discussions, and encouragement given by all these men have been very valuable in carrying on the problem of shear studies. Acknowledgment is also gratefully made for the interested cooperation of the entire laboratory staff, especially Messrs. C. H. Morris, C. W. Fletcher, and A. A. Wagner, for the development of testing equipment, testing procedure, and the performance of tests.

DISCUSSION

Mr. Gregory P. Tschebotareff.[1]—I have noted that all the papers on the triaxial test refer exclusively to granular materials. I should be interested to know whether any of the authors have conducted tests on cohesive soils.

Mr. John D. Watson.[2]—I have run one series of triaxial compression tests on a silt. This material was only slightly cohesive. The results of these tests were given in a report which I submitted to the U. S. Engineer Office at Providence, R. I. last year. At the present time a considerable number of triaxial compression tests are being made on various clays in the Soil Mechanics Laboratory of Harvard University. These tests are necessarily slow because of the long period of time which is required for the accomplishment of complete consolidation between each increment of load. It will, therefore, be some time before any results of these tests will be available for publication.

Mr. William S. Housel.[3]—I should like to ask Mr. Taylor a question in connection with his comparison between the direct shear test and the stabilometer test. Mr. Taylor at one point said that the results of the direct shear test were so erratic that he was not going to present them, but did show some comparisons in the tables between the direct shear test and the stabilometer test. I was confused as to which ones were presented and which were not.

Mr. Donald W. Taylor.[4]—None of the results obtained by the direct shear method was erratic. The only mention of erratic results was in reference to ultimate values by the cylindrical (or stabilometer) method. After passing the peak point in this type of test, the strains do not remain uniform throughout the sample and results are no longer dependable. Mr. Watson made a statement to the same effect. We frequently show the latter stages of the curve by dotted lines (for example Fig. 5(*b*) of my paper)[5] to indicate this.

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[1] Assistant Professor of Civil Engineering, Princeton University, Princeton, N.J.

[2] Research Fellow in Soil Mechanics, Graduate School of Engineering, Harvard University, Cambridge, Mass.

[3] Associate Professor of Civil Engineering, University of Michigan; Research Consultant, Michigan State Highway Dept., Ann Arbor, Mich.

[4] Assistant Professor of Soil Mechanics, Department of Civil and Sanitary Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

[5] See p. 1062.

RESEARCH IN SOIL STABILIZATION WITH EMULSIFIED ASPHALT

BY C. L. MCKESSON[1]

SYNOPSIS

Soil stabilization with emulsified asphalt has come into extensive use during the past five years. The usual tests for soil constants cannot be made on stabilized soils. Test methods by which the efficiency of stabilization could be measured were necessary. The development of such methods is described, and their use and interpretation explained.

Two of these test methods, the absorption test and the test for stability after absorption, are now in general use and have been recommended for publication as tentative by Subcommittee V on Methods of Testing for Stabilized Soils of the Society's Committee D-18 on Soils for Engineering Purposes.[2] A punching shear test is also described which, it is believed, may bring out additional information of value.

The test methods described are used to show relative efficiency of different types of emulsified asphalt as stabilizers, as well as to determine quantities required for stabilization.

DEVELOPMENT OF TEST METHODS

Soil stabilization with emulsified asphalt first came into general use in 1934. Prior to that time, several experimental projects had been constructed in which earthy materials were mixed with emulsified asphalt and produced durable bases having surprisingly satisfactory load-bearing properties. One of the largest of these projects, at the Glenn Martin Airport, in Baltimore, constructed in 1930, is still in use and giving splendid service.

Prior to 1934, no test methods were available by which probable success or failure could be forecast, or by which the required percentage of emulsified asphalt, or the relative efficiency of different emulsified asphalts could be predetermined. The success of the early projects was, therefore, merely good luck. As a result of research studies during 1932 to 1934, it became apparent that each soil stabilized differently and that the amount of emulsified asphalt required for different soils varied widely. It also became apparent that the effectiveness of stabilization varied with the consistency of the asphalt used in making the emulsion, and that even with the same asphalt, different types of emulsion varied widely in efficiency.

It was obvious that test methods were needed which would measure the effectiveness of stabilization, properly evaluating each variable, and thus making possible the design of economical stabilized base mixtures, with assurance that the base so constructed would give satisfactory service.

The conventional tests for soil constants proved unsatisfactory, as they assume the use of natural soil which is readily water-wetted. In this process of stabilization, each soil particle is provided with a water-repellent nonabsorptive asphaltic film.

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[1] Director of Engineering and Research, American Bitumuls Co., San Francisco, Calif.

[2] See p. 496.

The first test for determining efficiency of stabilization was an absorption test made by submerging stabilized samples in water for various periods of time. Submersion was not found to be satisfactory because stabilized fine clay soils with minute pores absorbed water more slowly than did gravelly soils or quarry soils or quarry fines—soil mixtures which had larger pores. The submersion test, in which the pores (or "voids") were filled under hydrostatic pressure, tended to show fine clayey soils to be superior to naturally stable granular material, and this was obviously incorrect.

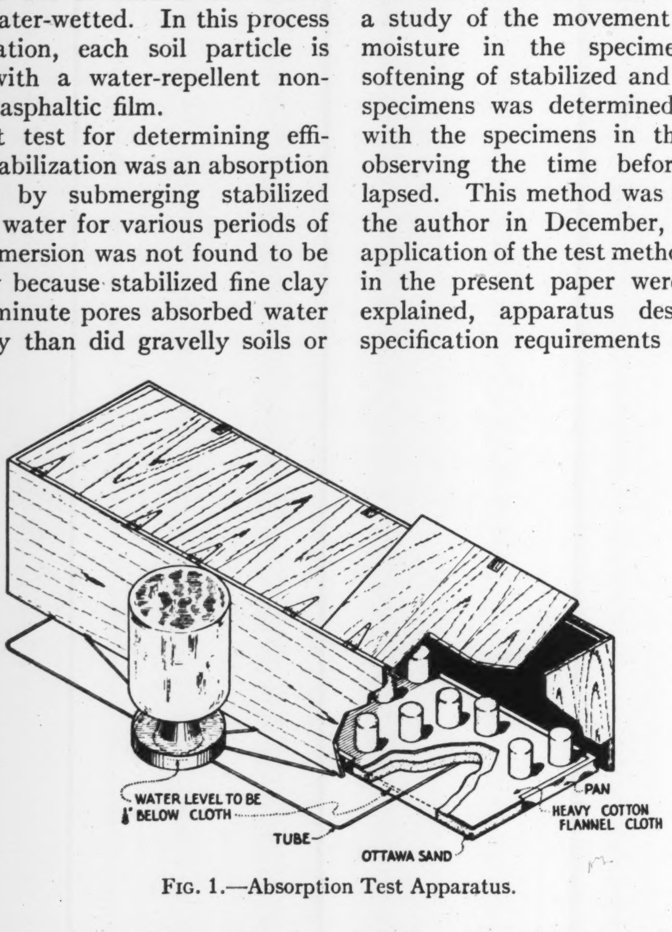

FIG. 1.—Absorption Test Apparatus.

The next test consisted of molding 2 by 4-in. cylinders of unstabilized and stabilized soil, and placing them in shallow pans with the lower ½ in. submerged in water. The 4-in. height of specimen was selected because this is the minimum thickness of a stabilized base and also because it permitted a study of the movement of capillary moisture in the specimen. Relative softening of stabilized and unstabilized specimens was determined by loading with the specimens in the bath and observing the time before they collapsed. This method was described by the author in December, 1935.[3] The application of the test methods described in the present paper were also there explained, apparatus described, and specification requirements discussed at length. Allowable space does not permit of repetition here.

THE PRESENT ABSORPTION TEST

The next development in absorption apparatus was intended to simulate as closely as possible exposure on a saturated, undrained subgrade in which the underside of the base is continuously in contact with a film of water. At first, a pan was filled with clay and the clay kept continuously saturated. The 2 by 4-in. stabilized and unstabilized cylinders were molded and compacted, dried to a constant weight at 140 F., and then placed on an absorbent paper cover on the clay. It was found difficult to keep the clay uniformly saturated and the pan was next filled by placing a layer of sand, a cloth membrane, a layer of diatomaceous earth, and a final cover of an absorbent blotting paper. A syphon feed was provided to maintain the water level at the underside of the blotting paper.

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[3] C. L. McKesson, "Soil Stabilization with Emulsified Asphalt," *Proceedings*, Highway Research Board, December, 1935, p. 365

In 1934, it was discovered that evaporation from the sides and top of the 2 by 4-in. specimens tended to reduce the ultimate absorption of stabilized specimens, due to continuous evaporation losses. The absorption pan was, therefore, placed in a cabinet and, in addition, each specimen wrapped on the sides and top with rubber, cellophane, or foil, to prevent evaporation and to approximate an extreme service condition in which the stabilized mass is resting on a sub-grade covered with free water, surrounded by water-impervious material and covered with a waterproof surface.

It was found that the layer of diatomaceous earth was unnecessary, and standard Ottawa sand, graded to a maximum voidage, was substituted and used for the full 1-in. depth. The next, and last, change was to substitute heavy cotton-flannel cloth for the blotter as a cover for the sand. This was done because it was discovered that blotters frequently have a high water-soluble mineral salt content, and this affected the rate of absorption and stability of the specimen. The present absorption test apparatus is shown in Fig. 1. Parallel tests are always run on stabilized and on unstabilized specimens.

TABLE I.—RATE OF ABSORPTION WITH TYPICAL SOILS, PER CENT.[a]

Absorption, days	Same Emulsion, Various Soils								Uniform Percentage of Different Emulsions with Varying Efficiency in Soil No. 3		
	Unstabilized				Stabilized						
	Soil No. 1—Sand Clay	Soil No. 2—Black Clay	Soil No. 3—Yellow Sand Clay	Soil No. 4—Black Clay	Soil No. 1—Sand Clay	Soil No. 2—Black Clay	Soil No. 3—Yellow Sand Clay	Soil No. 4—Black Clay	Emulsion (*a*)	Emulsion (*b*)	Emulsion (*c*)
1	14.4	24.3	18.1	16.2	0.5	1.3	0.4	0.8	0.45	0.37	0.88
4	16.2	35.0	19.0	26.5	1.0	2.5	1.1	1.4	0.76	0.59	2.44
5	16.5	....	19.0	29.8	1.2	3.4	1.1	2.2	....	....	....
7	*17.0*	....	*19.2*	*30.2*	*1.4*	*5.0*[b]	*1.5*	*3.2*	*1.00*	*0.81*	*3.40*[b]
12	18.1	....	19.3	30.4	2.0	5.9	1.9	3.9	....	....	....
15	18.1	....	19.3	30.7	2.0	7.0	2.0	4.8	1.54	1.14	6.29
19	18.3	....	19.3	31.0	2.1	7.6	2.0	5.3	....	....	....
21	18.5	....	19.3	31.2	2.3	8.5	2.4	5.9	1.90	1.75	8.20
25	18.5	....	19.3	31.2	2.5	9.2	2.4	6.5	....	....	....
29	18.7	39.4	19.3	31.7	2.6	10.1	2.4	7.5	2.19	1.99	9.97
32	....	....	....	....	....	....	....	....	2.29	2.13	10.59
49	....	....	....	....	....	....	....	....	2.70	2.57	11.87
71	....	....	....	....	....	....	....	....	3.01	2.98	12.49
91	....	....	....	....	....	....	....	....	3.25	3.23	....

[a] Absorption based on dry weight of soil.

[b] Present specifications limit the allowable absorption of treated specimens to 12 per cent of the untreated absorption, plus ½ per cent. The tests thus indicated are below present requirements.

Period of Absorption:

At first, the specimens were allowed to remain on the absorption pad for varying periods up to 90 days, but it presently developed that the results in 7 days indicated with certainty whether stabilization was effective, and obviously the shortest time which will give reliable results is desirable.

Table I shows absorption tests of various duration up to 91 days on four typical soils. In this table it will be observed that unstabilized samples almost complete their absorption in 24 hr. and in no case is there any

TABLE II.—RELATION OF ABSORPTION TO STABILITY.

Sample			Plastic Index	Mechanical Analysis, Total Percentage Passing				Emulsion, per cent	Tests of 2 by 4-in. Cylinders			Tests of Three Lower ½-in. Strata at 7 Days[a]													Ratio Columns (h) to (g)
									Absorption, 7 Days, per cent		(b) as Percentage of (a)	Moisture Content, per cent						(e) as Percentage of (d)	Stability (Total Load), lb.						
												Unstabilized			Stabilized				Unstabilized			Stabilized			
Soil	Laboratory Test Number	Source		No. 10 Sieve	No. 200 Sieve	0.005 mm.	0.001 mm.		Unstabilized	Stabilized		First	Second	Third	First	Second	Third		First	Second	Third	First	Second	Third	
									(a)	(b)	(c)	(d)			(e)			(f)	(g)			(h)			(i)
No. 1.....	2-264	Missouri	....	100	99	....	....	15	34.3	1.4	4	38.4	38.7	36.5	4.0	5.2	1.8	4	0	0	0	14 000+[b]	14 000+	14 000+	14 000+ to 0
No. 2.....	2-261	California	....	40	7.6	....	....	3	15.6	0.8	5	21.1	12.1	11.1	3.8	1.3	1.2	18	9000	14 000+	14 000+	14 000+	14 000+	14 000+	14 000+ to 9000
No. 3.....	2-249	Arizona	....	96	20.5	....	....	3.1	15.7	2.7	17[c]	22.5	21.0	16.3	6.4	3.4	3.4	20	5500	7 800	1 000	14 000	14 000+	14 000+	14 000 to 5500
No. 4.....	2-250	Arizona	....	99	30.1	....	....	4.5	16.2	4.7	29[c]	16.3	16.3	13.6	14.5	11.9	4.9	30	650	500	750	2 000	6 000	10 000	2 000 to 650
No. 5.....	2-241-1	California	5.3	100	65.8	22	14	7.2	9.9	1.0	10	12.9	11.9	11.4	1.5	1.9	0.7	12	3000	4 000	4 500	14 000+	14 000+	14 000+	14 000+ to 3000
No. 6.....	2-241-4	California	33.5	100	91.9	50	13	13.8	25.1	3.8	15[c]	34.0	29.4	29.9	31.2	11.4	3.7	90	0	0	50	8 700	14 000+	14 000+	8 700 to 0
No. 7.....	2-241-11	California	0	100	27.4	10	5	3.3	13.7	1.3	10	18.2	17.1	12.6	9.5	0.7	1.3	50	7200	7 200	8 500	14 000+	14 000+	14 000+	14 000+ to 7200
No. 8.....	2-1359-2	California	....	Field Samples 4 yr. Later				4.5	12.6	0.8	6	....	....	....	....	....	....	....	4000	9 000	18 000	40 000+	40 000+	40 000+	40 000 to 4000
No. 9.....	2-51-6B	California	33	100	90	46	24	12	31.7	3.1 7.4[d]	10 23[d]	36.0	32.7	31.0	21.1	7.5	4.5	51	0	0	0	14 000+	14 000+	14 000+	14 000 to 0
No. 10.....	2-469C	California	12	100	55	27	18	9.2	14.9	2.0	13	11.4	12.0	11.0	3.2	4.1	2.7	30	500	600	1 000	14 800	13 800	19 600	14 800 to 500
No. 11.....	2-350	Missouri	....	72	66	....	....	10.8	21.3	2.1	10	21.6	22.7	22.5	3.1	0.6	0.4	14	200	300	450	14 000+	14 000+	14 000+	14 000+ to 200
No. 12.....	2-235	California	....	100	70	....	....	7	20.7	3.5	16[c]	23.0	22.8	23.3	15.8	....	....	69	500	400	400	12 000	14 000+	14 000+	12 000 to 500
No. 13.....	2-308	Alabama	1.5	100	38	7	3.5	4.7	22.2	1.4	7	28.0	31.2	29.8	1.6	1.1	1.1	6	3000	7 000	12 000	14 000+	14 000+	14 000+	14 000 to 3000
No. 14...	A-100-2	Arkansas	....	72	13	....	....	4.0	12.5	1.5	12	16.3	14.3	11.1	3.1	0.7	0.4	20	4900	9 500	14 000	25 000	26 000	14 000	25 000 to 4900
No. 15.....	2-426	New Mexico	....	100	89	31.5	12.6	13.7	23.1	1.8	8	23.5	23.1	23.0	4.6	0.9	0.6	20	500	600	700	14 000+	14 000+	14 000+	14 000+ to 500
No. 16.....	2-409	Nevada	....	93	58	....	....	5.0	24.0	4.7	20[c]	25.8	22.5	21.8	13.2	9.2	2.2	50	0	0	0	5 800	14 000+	14 000+	5 800 to 0
No. 17.....	....	....	....	....	....	....	....	9.0	24.0	2.6	11	25.8	22.5	21.8	12.2	1.8	0.9	49	0	0	0	14 000+	14 000+	14 000+	14 000 to 0
No. 18.....	A-51	New York	....	86	74	....	....	11.1	28.8	4.0	14	30.0	30.5	29.7	15.6	3.6	0.6	50	0	0	0	11 100	14 000+	14 000+	11 100 to 0
No. 19.....	2-400	New Jersey	....	79	16	....	....	2.4	16.0	0.8	5	16.0	16.0	15.9	1.9	0.4	0.2	12	3100	3 370	4 240	32 100	49 610	49 810	32 100 to 3100
No. 20.....	2-51-6B	Colorado	....	100	65	21	11	4.0	18.7	1.6 2.6[d]	9 14[d]	21.0	18.6	18.4	4.4	1.8	2.0	25	100	150	300	14 000+	14 000+	14 000+	14 000+ to 100

[a] The strata are numbered from the bottom of the 2 by 4-in. cylinder, the first ½ in. being the stratum first extruded in the stability test.

[b] Stability tests were run to 14,000 lb. total load at the time these tests were made. 14,000+ indicates that this load was insufficient to extrude the stratum.

[c] Below present allowable absorption limit of treated specimens of 12 per cent of the untreated absorption plus ½ per cent.

[d] 29-day results—these tests were run 7 and 29 days for absorption. Stability tests were run at 29 days only.

significant gain after 7 days. Stabilized specimens usually absorb about one-third as much in 7 days as in 90 days. This gain is based on the dry weight of the entire specimen. However, it is the bottom ½-in. stratum of the 2 by 4-in. specimen which is later tested for stability, and it is, therefore, the critical portion of the specimen. This bottom stratum usually absorbs in 7 days approximately its ultimate water content and as much as it will ever take up in the field.

It will be observed in Tables I and II that the percentage of water absorbed in 7 days in properly stabilized specimens is between 10 and 15 per cent of the percentage of water absorbed by unstabilized specimens in the same period.

TABLE III.—COMPARISON TEST RESULTS OF PRECONSTRUCTION TESTS AND TESTS AFTER COMPLETION.

Group	Location	Preconstruction Tests[a]					Project Samples			
		Number of Projects	7-day Absorption, per cent		Stability after 7-Day Absorption, lb.[b]		Age when Sampled, yr.	Average Field Moisture Content, per cent	Stability with Field Moisture, lb.[b]	Condition of Projects
			Untreated	Treated	Untreated	Treated				
1	New England	3	N.T.	N.T.	N.T.	N.T.	3	5.80	21 400	Good
2		4	10.2	0.99	6725	25 860	2	4.76	28 615	Good
3		1	13.65	0.63	8120	22 800	2	7.31	15 500	Good
4		2	10.18	1.04	6310	24 400	1	9.12	25 087	Good
5	Mid-Southern	2	N.T.	1.4	N.T.	31 000	2	9.75	15 000	Good
6		2	15.64	2.9	2000	18 750	1	7.1	19 000	Good
7	South Atlantic	1	11.54	3.8	3250	7 140	0.5	6.04	8 550	No base failures[c]

[a] N.T. = No tests made.

[b] Bottom ½ in.

[c] Surface cold mixed asphaltic concrete. 1½ per cent surface failures where surface averaged ⅝-in. thickness. No failures where surface is 1 in. or more in thickness.

Allowable Percentage of Absorption:

Based on thousands of laboratory tests and continuous performance studies in the field, specifications were prepared and are now in general use, limiting the maximum allowable moisture content in stabilized specimens after the 7-day absorption test to 12 per cent of the moisture in an untreated specimen at 7 days, plus ½ per cent.

Applied to the four soils in Table I, this gives a maximum allowable moisture content in stabilized specimens for the four soils, as follows:

Soil (See Table I)	Maximum Allowable Moisture Content After 7 Days Absorption, per cent
No. 1—Sand clay	2.54
No. 2—Black clay	4.70
No. 3—Yellow sand clay	2.30
No. 4—Black clay	4.13

It will be found, upon comparing the above tabulation with Table I, that results obtained on two of the samples would not be considered satisfactory under generally prevailing specifications. Results of tests on 20 typical soils are shown in Table II. Here, also, it is noted that some of the tests, as indicated are outside the allowable specification limits. Of these, tests on soils Nos. 3, 6, and 12 are only slightly higher than the allowable maximum absorption, and these soils also make a fair showing in the stability test, hereinafter described.

In Table II, moisture content is also shown for the lower three ½-in. strata of each stabilized and unstabilized specimen.

In 1938 a nation-wide survey was made of emulsified asphalt stabilized projects one to four years old, most of which were designed on data obtained from the test methods herein discussed. The field moisture content was determined and also the stability of samples with field moisture content present at the time of test. The results on a number of typical projects are shown in Table III. In this table it will be found that the preconstruction tests indicated efficient stabilization and that the field moisture was in general similar to the moisture content of the bottom ½-in. stratum of the satisfactorily stabilized specimens in Table II.

TABLE IV.—THE EFFECT OF DRYING AND MOISTURE CONTENT ON STABILITY.
San Francisco Clay Soil.

Description	Stabilizer, per cent	Water Absorbed in 7 Days, per cent	Total Water at Test, per cent	Stability, lb.		
				First ½ in.	Second ½ in.	Third ½ in.
Specimen dried at 140 F. Regular absorption and stability procedure	0	13.3	13.3	500	500	750
	0	12.7	12.7	500	500	750
	0	12.5	12.5	750	1 000	1 000
Average	0	12.8	12.8	583	666	833
Specimen dried at 140 F. Regular absorption and stability procedure	10	1.2	1.2	25 000	37 000	40 000+
	10	1.4	1.4	24 000		
	10	1.3	1.3	24 000		
Average	10	1.3	1.3	24 333		
Specimen air-dried to 5 per cent moisture content, then absorption and stability	10	1.9	6.9	5 000	8 000	9 500
	10	2.1	7.1	4 000	5 500	6 500
	10	2.1	7.1	5 500	8 500	10 000
Average	10	2.0	7.0	4 833	7 332	8 666

MECHANICAL ANALYSIS

Sieve Size	Percentage Passing	Sieve Size	Percentage Passing
½ in.	.....	No. 80	72.1
¼ in.	.....	No. 200	52.0
No. 10	100.0	0.005 mm.	19.3
No. 40	95.5	0.001 mm.	10.3

Plastic index 10.

Necessity for Compaction:

In preparing the specimens for the absorption test and subsequent stability and shear tests, it is necessary that they be molded at a moisture content which will produce dense specimens, just as it is necessary, in construction, that the stabilized base mixture be properly compacted. In construction, this compaction is obtained with sheeps-foot and rubber-tired rollers, with the moisture content at or about the optimum for maximum compaction. In preparing test specimens, compaction is obtained by recompressing after molding and partial drying, under a total load of 3000 lb.

Dehydration:

Soil stabilization with emulsified asphalt assumes that the asphalt present in minute particles in the emulsion is to be dispersed among the soil particles during the mixing operation, and subsequently drawn into a film over each soil particle during dehydration by the surface tensions developed while the moisture film is evaporating. Many data have been developed to substantiate this theory. In any event, it is amply proven that fully efficient stabilization does not occur until the stabilized mixture has been dried, and thorough drying results in higher stabilities, as well as high resistance to subsequent absorption.

The effect of the presence of moisture in the specimens when they are placed in the absorption cabinet is shown in Table IV. In this table, specimens which were dried to a constant weight in the conventional way at 140 F. show an average absorption in 7 days of 1.3 per cent. Specimens dried to 5 per cent moisture content show an absorption of 2 per cent in 7 days and a total moisture content at time of test of 7 per cent. The stability of the specimens is affected to a much greater extent—the stability of the properly dried specimens after 7 days absorption being over 24,000 and the stability of the specimens dried to 5 per cent moisture content being slightly less than 5000 lb. Thorough drying at 140 F. is, therefore, provided as one of the test conditions in order that this variable may be entirely eliminated, and comparisons may be made of the degree of efficiency due to variations in emulsion content and also, if desired, to determine differences of efficiency of different types of emulsified asphalt used as stabilizer.

Stability Test

The stability test was developed in 1935 and, with the absorption test, has been almost universally specified on stabilization projects since that time. Many millions of square yards of stabilized base have been designed and constructed, based solely on the results obtained from these two simple tests. The generally successful performance of work so constructed justify the assumption that the physical properties measured by these test methods are indicative of the efficiency of the stabilization.

The apparatus used in this test is shown in Fig. 2. In the test the 2 by 4-in. specimen, after being tested for absorption, is placed in the testing cylinder, with wet end downward. A seating load of 3000 lb. is applied while the bottom orifice plate is closed with the plug. The plug is then removed and load applied until the plunger has been moved downward $\frac{1}{2}$ in., extruding a portion of the cylinder. The total load in pounds required to move the plunger $\frac{1}{2}$ in. is reported as the stability for that $\frac{1}{2}$-in. stratum.

The stability test is intended to measure the resistance of stabilized and unstabilized soil or soil-aggregate mixtures to displacement or plastic flow after they have been subjected to absorption. Clayey soils, unstabilized, offer little resistence to plastic flow when wet. Plastic flow is evidenced by rutting in wet earth roads. Granular soils with a controlled clay content show a much higher resistance to the same type of displacement, and properly stabilized soils show an extremely high resistance, even in the presence of percentages of moisture which would produce instability in the same soil or soil-aggregate mixture, unstabilized.

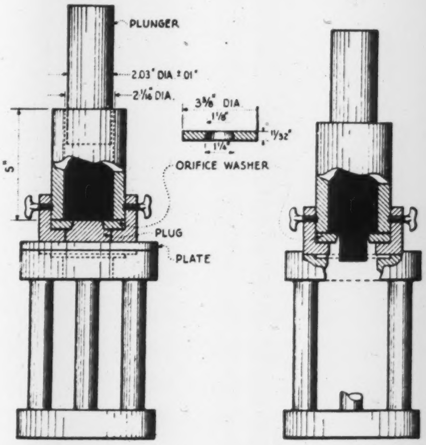

Fig. 2.—Stability Test Apparatus.

Assembled at left for preliminary seating load of 3000 lb. Assembly at right as used in stability test with section broken away to illustrate extrusion of soil specimen.

The effect of stabilization on plasticity, as measured by the stability test, is shown in a number of the tables. Particular attention is called to Table II which shows the stability of the specimens as evidenced by the resistance to displacement of each of the three lower ½-in. strata. The moisture content of each stratum is also shown. The table includes results of tests on both stabilized and unstabilized specimens.

TABLE V.—EFFECT OF HEIGHT OF SPECIMEN ON ABSORPTION AND STABILITY.

A-2 Soil. Liquid limit 19. Plastic index 2.

Emulsion, per cent		Total Percentage Water Absorption	Total Absorption as Percentage of Untreated Absorption	Stability Test, Bottom ½ in., lb.	Length of Absorption Period, days
Height, in.	On Total				
1.12	0	28.1	100.0	3 100	72
1.15	0	22.1	100.0	2 300	7
1.43	0	22.3	100.0	4 600	72
1.45	0	19.3	100.0	4 300	7
2.83	0	21.3	100.0	4 500	72
2.85	0	18.0	100.0	6 000	7
1.08	6	6.0	21.4	16 000	72
1.07	6	3.5	15.8	18 500	7
1.73	6	3.5	15.7	24 000	72
1.74	6	2.4	12.4	22 300	7
2.80	6	3.0	14.1	22 000	72
2.80	6	1.8	10.0	26 500	7

TABLE VI.—EFFECT OF WALL FRICTION IN THE STABILITY TEST.

Material	Unstabilized, 7-Day Aborption, per cent	Stabilized			
		Emulsion, per cent	7-Day Absorption, per cent	Regular Test Method, Bottom ½ in., Stability, lb.	Special Test Method, Bottom ½ in., Stability, lb.[a]
Logan Quarry Fines	11.6	4.8 6.0	1.4 1.1	30 500 32 250	37 500 37 250
Clover Field Soil	9.7	4.3 5.4	0.7 0.7	40 000+ 38 500	31 500 35 000
San Francisco Clay-Sand	12.7	6.3 7.9	1.8 1.4	13 250 20 000	11 000 20 000

[a] Special test method eliminating wall friction.

The effect of stabilization in changing the plastic flow properties of a soil without greatly changing its capillary absorption is strikingly illustrated by soil No. 6 in Table II, which is an extreme case. It will be noted that after 7-day absorption, the moisture content of the bottom ½-in. of the unstabilized specimen is 34 per cent. The moisture content of the bottom ½-in. of the stabilized specimen is 31.2 per cent, or 90 per cent as great. However, in the stability test, the bottom ½-in. stratum of the unstabilized soil shows zero resistance to displacement, and the stabilized bottom ½ in. shows a resistance to displacement of 8700 lb.

When the stability test was devised in 1935, it became possible for the first time to evaluate definitely the changes in the stability of a soil or soil-aggregate mixture brought about by stabilization.

Effect of Height of Specimen:

Studies have been made of the effect of variations in the height of the specimen—both on absorption and on stability. Table V shows the result of a series of these tests made in the Soils Laboratory of the Texas Highway Department, under the direction of W. H. Wood, Materials Engineer, on unstabilized and stabilized specimens.

In the stabilized specimens, it is to be especially noted that the increase in absorption, between 7 and 72 days, is not reflected by a greatly diminished stability. This is pointed out earlier in this report as probably due to the fact that the bottom ½-in. stratum reaches its maximum water content in 7 days, and it is this stratum which is tested for stability.

It would appear from Table V, and also from other work not included herein, that the height of the specimen is not critical in so far as it affects stability.

Stability Requirements:

When this method of test was developed, specifications were written providing for a minimum stability of the bottom ½ in. of 10,000 lb. This was based on stabilities shown when highly satisfactory waterbound base materials were tested by the same method. Exceptionally good materials used in base construction, such as selected quarry fines, were found to give a stability, untreated, of 5000 to 8000 lb., with an occasional specimen up to 10,000 lb. Selected subbase materials in general use were found to have stabilities ranging from 2500 to 7000 lb. Soils which are considered good subgrade material usually ranged from 500 to 3500 lb., and clayey soils from zero to 500 lb.

During the first two years the test was in general use, it was thought that stabilization could be called successful if the total load necessary to extrude the bottom ½ in. exceeded 10,000 lb., and the tests were ordinarily stopped when the load reached 14,000 lb. This accounts for the many items in Table II which show 14,000 plus. During the past three years, stability tests have usually been run to 40,000 lb. if necessary to obtain displacement of the bottom ½ in., and some additional information of value has been obtained.

Effect of Frictional Resistance in the Testing Cylinder:

In view of the high lateral pressure set up in making the stability test and the high total loads observed at the extrusion of each successive stratum, a study was made to ascertain whether these results were influenced by frictional resistance between the sides of the specimen and the inside of the testing cylinder. In order to eliminate possible wall friction, a special modified test was devised in which the orifice plate was moved into the cylinder so that the soil specimen did not slide against the testing cylinder wall. Tests on identical specimens were run by the special method as well as by the regular stability method. The comparative results of these tests are shown in Table VI. Although in the special test the specimen in the cylinder remained stationary and, therefore, there could have been no friction due to the sliding of the specimen in the cylinder, the results by the special test method are not appreciably different from those ob-

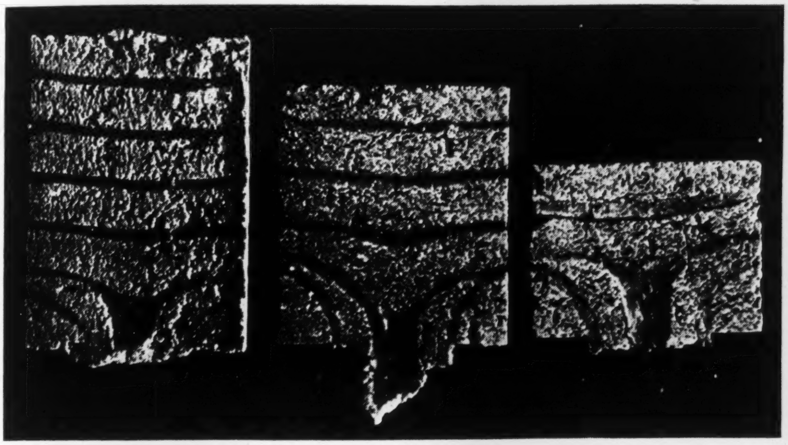

FIG. 3.—(From left to right.) Cross-sections of a Specimen After the Extrusion of ½ in., 1 in., and 1½ in. in the Stability Test.
At the beginning of the test the dark lines were equally spaced and parallel.

tained in the regular stability test. This indicates that wall friction is not an important factor and that the measured resistance to extrusion in the regular stability test is produced principally by internal resistance to plastic flow within the soil cylinder.

This has also been demonstrated by making soil specimens with alternate strata slightly colored and then removing the specimens from the testing cylinder after ½ in., 1 in., and 1½ in. had been extruded. Figure 3 shows these cylinders sawed open. The movement which had occurred in the interior of the specimen is clearly shown by the directions assumed by the colored strata. These sawed specimens show that the plastic flow is greatest in the center of the specimen. (This study was first made by W. H. Wood and acknowledgment is here gratefully made.)

TABLE VII.—RELATION OF PUNCHING SHEAR TEST TO STABILITY TEST.

Material	Unstabilized			Stabilized				Remarks
	Absorption in 7 Days, per cent	Stability, Bottom ½ in., Total Load, lb.	Punching Shear, Total Load, lb.	Emulsion, per cent	7-Days Absorption, per cent	Stability, Bottom ½ in., Total Load, lb.	Punching Shear, Total Load, lb.	
Quarry fines (Calif.)	12.3	23 000	2375	4.8	1.2	30 500	16 000	An exceptionally high-grade base material.
				6.0	1.1	32 250	15 750	Very hard, tough stone, with good cementing value. 29 per cent passing No. 10 sieve. 41 per cent passing ¼-in. sieve.
Soil (Colo.)	21.4	150	150	9.0	3.3	10 000	14 750	99 per cent passing No. 10 sieve. 67 per cent passing No. 200 sieve.
				11.2	3.1	10 500	13 250	15 per cent passing 0.001-mm. sieve.
Soil (Calif.)	13.1	800	275	6.3	1.8	13 250	14 000	100 per cent passing No. 10 sieve. 52 per cent passing No. 200 sieve.
				7.9	1.4	20 000	16 250	10 per cent passing 0.001-mm. sieve.

PUNCHING SHEAR TESTS

In May, 1937, A. T. Goldbeck, in the *Crushed Stone Journal*, reported results of punching shear tests on stabilized base mixtures. The method proposed at that time consisted of molding specimens 2⅝ in. in height and 4 in. in diameter and subjecting them to shear with a 2-in. plunger on top of the specimen and a 2¼-in. diameter aperture in the plate underneath the specimen.

Experimental work with a number of soils and with quarry fines, following the method proposed by Goldbeck and a modification of this method in which the height of the specimen was increased to 4 in. indicated that some additional useful information might be obtained by a punching shear test. Subsequently, the same general principle was utilized in devising a punching shearing test for 2 by 4-in. specimens identical with those used in the stability test. In this test, a 1-in. plunger is substituted for the 2-in. plunger used in the stability test. The apparatus is otherwise identical.

As the soil specimens are slightly smaller than the inside of the test cylinder, limestone dust is vibrated into the space between the testing cylinder and the specimen prior to the test. The load is then applied on the 1-in. plunger centered on the soil specimen directly over the 1⅛-in. orifice in the bottom, until the maximum is reached. The results of punching shear tests made by this method and their relationship to stability tests are shown in Table VII.

The gradation of the soil or aggregate used and the angularity of the particles appear to have a substantial effect on the total load in the punching shear test, especially on unstabilized specimens. Although this test method has not as yet been used in specifications, it is believed that it may be distinctly useful in research work and may eventually be utilized in specifications.

Use of the Test Methods in Research and Design

The test methods described are used in routine preconstruction studies to secure maximum efficiency of stabilization at minimum cost. Separate sets of specimens are made with various quantities of emulsified asphalt as a stabilizer and with the different soils or soil-aggregate blends available. Selection is based on efficiency and cost.

The test methods have also been found useful for studies of the effect of other variables such as the kind and consistency of the bitumen used in the emulsion and of the effect on stabilization of variations in the type and quality of the emulsion.

Test results of such a study are shown in Table VIII, where the variable was the size of the asphalt particles in the emulsion. These tests show that fine particle size in an emulsion is an important property for effective stabilization. One emulsion had an average particle size of 47 μ, the other 2.9 μ. Ten per cent of the coarse emulsion is shown to be less effective than 4 per cent of the finely dispersed emulsion.

By the use of these test methods, the consistency of the bitumen used was found to be an important factor in the efficiency of stabilization.

The tests proved sensitive enough to differentiate between two emulsions in which the only difference was in the penetration of the asphalt used in the emulsion. Asphalt of 58 penetration at 77 F. is shown to be about 10 per cent more effective than an asphalt of 209 penetration.

TABLE VIII.—EFFECT OF EMULSION PARTICLE SIZE ON STABILITY AND ABSORPTION.

Type of Stabilizer[a]	Percentage of Stabilizer	Penetration of Residue	7-Days Absorption, per cent	Stability First ½ in., lb.	Punching Shear, lb.
None	0	...	12.3	416	183
Fine emulsion	4.0	53	2.4	11 000	11 083
Coarse emulsion		54	14.9	566	276
Fine emulsion	6.0	53	1.3	20 000	9 416
Coarse emulsion		54	13.8	1 166	333
Fine emulsion	8.0	53	1.1	23 000	14 000
Coarse emulsion		54	11.7	2 333	433
Fine emulsion	10.0	53	0.9	20 333	10 586
Coarse emulsion		54	6.1	5 766	2 750

[a] Fine emulsion—average particle size = 2.9 μ
Coarse emulsion—average particle size = 46.7μ

The results of stability or punching shear tests cannot yet be utilized in formulas for determination of thickness of stabilized bases, but it is hoped that by relating the results of these tests made on base and subsoil samples with field performance and similar tests on field samples after construction, it may in time be possible to evolve an empirical formula for structural design. Studies looking to this end have been under way for over a year.

DISCUSSION

Mr. Miles S. Kersten[1] (*presented in written form*).—The writer recently used the stability test procedure described by Mr. McKesson in a laboratory study of bituminous-soil mixtures. Various types of bituminous materials other than emulsions were used. These were incorporated with a silt loam soil at different moisture contents. The stability test portrayed very well the benefit of an increase in mixing water, although the absorption results showed little variation. This benefit resulted from the increased density attained and the better bitumen distribution afforded by the higher moisture contents. The range of mixing waters investigated was from 4 to 20 per cent.

One factor of the stability test of considerable importance is not discussed by Mr. McKesson. This is the 3000-lb. "seating load" applied to the specimen. For the more poorly stabilized specimens which have high absorptions, this results in a stability which may be somewhat misleading. The initial pressure results in a part of the water contained within the specimen being forced from the soil and the specimen being tested becomes, as a consequence, drier and more compact. As a result, it is more stable than it was at the conclusion of the absorption test. In tests run by the writer, specimens which were so unstable when removed from the absorption bath that they hardly held their shape, or apparently had "zero stability," often gave stabilities of around 4000 lb. after the initial pressure of 3000 lb. had been applied. In Table II of Mr. McKesson's paper, numerous results of zero stability are listed. It is difficult to understand such results on soil specimens which have been compressed under a 3000-lb. load in an apparatus which is by no means watertight.

Mr. McKesson has presented data which indicates that wall friction is not an important factor. It is the writer's belief that this item does affect the result which is recorded as stability, but that its significance is not great. Load caused by friction is apparently low in the tests of specimens giving low stabilities, since the moisture content of the soil is high. It is proportionately greater for those specimens giving higher stabilities, since these are usually in a drier condition. In tests performed by the writer, the test specimens were removed from the testing mold by removing the orifice ring and applying a load on the plunger. In this way the total frictional resistance between the specimen and the walls of the cylinder was noted. For specimens which gave fairly high stabilities (around 20,000 lb.) this load was often found to be several thousand pounds.

Mr. T. A. Fitch[2] (*by letter*).—The tests proposed have been in use by the City of Los Angeles for several years, and experience shows that they do not establish the efficiency of stabilization. Some emulsions which comply with all of the proposed requirements produce

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[1] Instructor of Civil Engineering, University of Minnesota, Minneapolis, Minn.

[2] Director, Bureau of Standards, City of Los Angeles Department of Public Works, Los Angeles, Calif.

"stabilized" soil that remains wet and becomes readily saturated with water so that lumps of it disintegrate. Such do not give "assurance that the base so constructed would give satisfactory service." Such do not agree with the claim that: "In this process of stabilization, each soil particle is provided with a *water-repellent non-absorptive* asphaltic film" (italics added). Such confirm the statement that: "fully efficient stabilization does not occur until the stabilized mixture has been dried."

The two test methods proposed for absorption and for stability do not rate service conditions. A drying temperature of 140 F. gives a quick test, but not a natural one. The absorption characteristics of some soils dried at 140 F. are radically different from the characteristics of those same soils dried at normal temperatures found in construction. Emulsified stabilized base, wet and plastic as removed for examination, has been found to become resistant to absorption after drying at 140 F. Moreover, the compaction (nearly 1000 psi.) of the proposed stability specimens has no counterpart in actual construction.

Emulsion stabilization is so patently experimental in status and the proposed tests so far from an evaluation that the need persists for the development of service tests to determine to what extent, and under what conditions, an asphalt emulsion will stabilize soil.

MR. RAYMOND HARSCH[3] (*presented in written form*).—Mr. McKesson's paper has been studied with considerable interest, as it contains data indicating the value of these methods of tests. I wish to refer to some practical applications which should create some doubt as to their suitability.

In regard to the tests themselves, I raise the following points:

Preparation of Specimens.—The specimens are dried at 140 F. until they reach constant weight. Such a condition is not even approached under field conditions, except under periods of drying which are felt to be impractical for most construction. Furthermore, the drying temperature of 140 F., being above the softening point of paving asphalt, can also create an asphalt film distribution entirely different from that which would occur at lower drying temperatures.

Absorption Test.—In this test the specimens are wrapped or protected from moisture on the sides and top by an impervious membrane, thus subjecting only the bottom of the specimen to moisture. It is felt that this makes the test one for capillarity and not absorption. Under the test the specimen does not reach absorption equilibrium in seven days as would be the case for total immersion or if the moisture surrounded the specimen. I have been informed by F. N. Hveem, of the California Highway Laboratory, that swell test values on specimens surrounded on the sides by damp sand were considerably greater than those obtained by a depth of water on the surfaces of specimens surrounded by the molding ring.

If the stability against moisture is only one of retarding or preventing capillary action from the bottom surface of the soil layer, is it not more easily and more surely accomplished by an asphaltic membrane between the subgrade and the soil layer? If absorption is the factor, total immersion is a more logical test method.

As the bottom of the emulsion stabilized layer is the last to reach the proper degree of dehydration, the effective depth of the stabilization is variable and difficult to determine practically.

The length of time required for emulsion-stabilized soils to lose their moisture under the best of drying conditions is surprising. A specimen, 6 in. in diameter and 1 in. thick, removed from the mold and allowed to dry on a shelf in laboratory air of 70 to 95 F., still retained 2 per cent moisture after 23 days. From this the drying time for a 6-in. depth on a damp subgrade can be visualized.

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[3] Assistant Manager, Asphalt Dept., Shell Oil Co., Inc., San Francisco, Calif.

Shear Test for Stability.—In discussing this test, I feel it necessary to discuss first the purpose of emulsion stabilization. Is it either necessary or desirable that the stabilized base develop a type of rigid structure approaching a portland cement concrete slab in which there must be sufficient clay binder to develop high cohesion? Such bases are in considerable contrast to stabilization using granular materials, or other types of bituminous mediums which permit flexibility.

If the rigid type slab is the aim, it is a question as to whether an extrusion shear test should be used. One would not think of recommending such a test for cement-concrete paving mixes. A cross-bending or compression test would appear more logical, especially the former, as that is the factor which produces failures in these types of bases. On that basis, the higher the cohesion, the stronger the slab, and large amounts of clay binder would be desirable.

My observations lead me to believe that the rigid type of base, unless it can be built thick enough and strong enough, is undesirable as a support for a bituminous wearing surface.

Cohesion is a minor factor in a base course, as evidenced by many miles of highways built on sand, sand gravel, crushed rock, cinders or other cohesionless materials. At least there is no real excuse for admixing clay into such materials in order that a bituminous material must be used to waterproof the clay. If cohesion is required, why not use the bitumen as the binder?

Conclusion.—From observation in the field, it is my impression that these tests are not producing the safeguards against failure that the data in this paper infer. I accordingly conclude that the methods being followed in designing the emulsion-stabilized bases are inadequate and unreliable. They apparently lack proper consideration of the principle by which the load is being transmitted to the underlying soil. These tests certainly do not determine how thick the stabilized base should be or how much the intensity of pressure is diminished through such a stabilized layer.

MR. C. L. MCKESSON[4] (*author's closure by letter*).—The author greatly appreciates the comment and criticism presented in the discussions by Messrs. Kersten, Fitch, and Harsch, because these indicated that some points were not made entirely clear in the paper, and should be further discussed. These points will be taken up in the order in which they are presented in the discussions.

Seating Load (*Stability Test*).—Mr. Kersten has observed that some moisture is frequently extruded during the application of the 3000-lb. seating load on unstabilized or poorly stabilized specimens after they have been subjected to the absorption test. He is entirely correct in this observation, but the author does not believe that this loss is of serious import, because the precise degree of stability of such specimens is relatively unimportant. Mr. Kersten comments on Table III in which some unstabilized specimens show zero stability. It will be observed from the the table that the soil in these specimens was extremely fine and had a very high clay content. These samples were very soft and plastic after the seating and extrusion tests. Samples extruded from the bottom $\frac{1}{2}$ in. of each specimen contained from 26 to 38 per cent of moisture. Even moderately stabilized specimens and good unstabilized materials have little or no free moisture loss in the seating test, and their stability is therefore affected to a very slight degree, if at all. Two years of experience with stability tests before the practice of applying a seating load was adopted and a similar period since then have indicated that stability results are not greatly changed by the application of the seating load, but that the results are somewhat less erratic and more reproducible when the seating load is used.

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[4] Director of Engineering and Research, American Bitumuls Co., San Franisco, Cailf.

In lieu of seating, the space between the specimen and the walls of the test cylinder is sometimes filled with rock dust vibrated into place. This practice seems to give higher stabilities but could be followed, if desired.

Wall Friction (Stability Test).—Mr. Kersten correctly observes that wall friction is to some extent recorded as stability but that its significance is not great. This is also indicated by Table VI in the paper.

Effect of Moisture on Efficiency of Stabilization.—Mr. Fitch does not believe that the described tests establish the efficiency of stabilization, because he has observed that some emulsions, which comply with all requirements, produce a soil that remains wet. Stabilized soil does dry somewhat more slowly than unstabilized soil, but the author has never seen a stabilized soil which would not dry out, if given time. Some emulsions dehydrate more rapidly than others, and some users therefore specify an emulsion with a high rate of dehydration, believing that this will accelerate the drying of the stabilized mixture. If a stabilized soil mixture could be produced which would "remain wet," as described by Mr. Fitch, it would not pass the proposed test requirements which are predicated on the drying of samples at the beginning of the test.

If Mr. Fitch is referring to stabilized base which remains wet because it was not given a sufficient opportunity to dry after compaction and before surfacing, then stabilization was not fully effective, and the disintegration which he says occurred in the presence of water should have been expected. This is a construction matter, and not a matter of testing, and it is believed that all specifications now require that stabilized base be allowed to dry after compaction. Tests made by the methods outlined, except by drying to the field moisture content instead of to constant weight at 140 F., would have indicated the inefficiency of such stabilization. The effect of moisture present in the specimens at the time the tests started is shown in Table IV. Proper dehydration is so indispensable that emphasis should be placed on the statement, quoted from the paper by Mr. Fitch: "fully efficient stabilization does not occur until the stabilized mixture has been dried." Only after drying is "each soil particle provided with a water-repellent asphaltic film . . . with assurance to the builder that the base so constructed will give satisfactory service."

Drying Specimens at 140 F. (Absorption Test).—Mr. Fitch believes that drying at 140 F. gives a quick test, but that some soils dried at this temperature have different characteristics than the same soils dried at normal temperature. The temperature of 140 F. was selected because it was believed that this temperature was low enough to avoid any structural or chemical changes in the soil, and it is recognized as a reasonable summer temperature in bituminous roads in many tests, such as the Hubbard-Field Stability Test, Hveem Stabilometer Test, etc., made on other bituminous materials. It was also found that this temperature is about as low as possible if specimens are to be dried to a constant weight within a reasonable period, usually about 7 days. While this temperature is usually used where the moisture content is to be eliminated as a variable, to permit of evaluating other variables, tests can be made in exactly the same manner, if the user prefers, by drying to a constant weight at any other temperature, or to a given moisture content, as shown in Table IV. Drying at 140 F. has come to be considered optimum drying, just as 28 days in the moist room is frequently considered as standard curing in cement concrete tests.

Compacting Specimens with a 3000-lb. Load.—Mr. Fitch questions whether compaction under a 3000-lb. load (about 1000 psi.) has any counterpart in actual construction.

Many tests have indicated that the density of specimens compacted in this manner closely approximates efficient compaction that can be obtained in the field. The average density of 58 laboratory-molded field-mixed specimens from the Los Angeles Municipal Airport was 119 lb. per cu. ft. The average dry weight per cubic foot of the same soil, unstabilized, when compacted by the Proctor method at optimum moisture content, was 128.3 lb. per cu. ft. Fifteen cores from the sheep's-foot compacted stabilized base have an average density, dry, of 122.9 lb. per cu. ft., or nearly 4 lb. per cu. ft. more than the laboratory 2 by 4-in. specimens compacted under the 3000-lb. load. A typical clay-gravel blend had a dry density by the Proctor method of 128.6 lb. per cu. ft., and laboratory specimens made and compacted in the manner described, with 2, 2½, and 3 per cent of emulsified asphalt stabilizer, had dry densities, respectively, of 128.0, 129.2 and 129.2 lb. per sq. ft. It seems that the method described does rather closely approximate field compaction and Proctor maximum density compaction.

Mr. Fitch believes that soil stabilization with emulsified asphalt is experimental. This theory would hardly be acceptable to many engineers in this country who have been constructing projects every year since 1934 with entirely satisfactory results. If by "experimental" Mr. Fitch means that this type of construction can be still further developed and improved, he is undoubtedly right. In this sense, all pavements are experimental.

Sealing Sides and Top (Absorption Test).—As Mr. Harsch points out, and as stated in the paper, the absorption test is for capillary absorption. One surface is exposed to the saturated subgrade, and sides and top of the specimen are sealed to prevent evaporation losses. This approximates the worst condition which could exist in any similar prism within a base on a saturated subgrade covered with an impervious surface. Sealing the top and sides against moisture losses makes the test much more severe than where moisture is permitted to escape by evaporation during the absorption period.

Mr. Harsch indicates a preference for submersion tests. Submersion tests would be reasonable for reservoir linings, but submersion is not a normal condition in a properly designed highway. Mr. Harsch quotes Mr. Hveem as saying that specimens buried in wet sand absorb more moisture than specimens confined in a molding ring with water on their surface. This, of course, is correct. A confining ring prevents a specimen from swelling laterally while taking moisture, and greatly reduces the absorption rate with swelling soils.

In the test described in the paper, the

2 by 4-in. cylinders were originally left in their molds, but it was soon determined that absorption was greatly retarded. Therefore, the specimens were merely wrapped in cellophane or rubber, and permitted to swell freely and to absorb water by capillarity, without restriction. Apparently, Mr. Harsch has lost sight of the fact that in the tests as described, the bottom $\frac{1}{2}$ in. of each specimen reaches a moisture equilibrium in the 7-day test, and it is this bottom $\frac{1}{2}$ in. which is tested for stability.

Stability Test.—Mr. Harsch's apparent unfamiliarity with emulsified asphalt stabilized base construction has evidently led him to believe that emulsified asphalt stabilized base is, or is intended to be, a rigid type of construction. Such, of course, is not the case. Under service conditions, any stabilized base takes up some moisture from capillary absorption, just as do the laboratory specimens in the 7-day absorption test. It therefore has plasticity (see Fig. 3) but the resistance to plastic flow with the anticipated field moisture content must be sufficient to prevent distortion and to distribute the load to the subgrade. Table III shows typical field moisture contents and stabilities at field moisture content in comparison with laboratory preconstruction test values.

Mr. Harsch states that he believes "that the rigid type of base, unless it can be built thick enough and strong enough, is undesirable as a support for a bituminous wearing surface." As above stated, and as clearly indicated by the test data in the paper, stabilized base is not a rigid type, but with stabilized base, as with any type, the base should be "thick enough and strong enough."

Mr. Harsch believes that cohesion is a minor factor in base courses, because highway pavements are successfully built over sand and other cohesionless subgrades. He overlooks the fact that the pavements constructed over such subgrades are not cohesionless. It is difficult to conceive of a serviceable pavement which would be cohesionless.

Stabilized base is a part of the pavement, and is usually covered with a relatively light bituminous wearing surface. Cohesion is therefore a desirable property.

The author does not intend to imply that the test methods described are the only ones which could be devised and confidently expects that new methods will be developed which will be found useful, and results from which can be used even more directly in design formula. The tests described are, however, the only ones which have been in general use, and they have been used on hundreds of projects in the past five years. By comparing tests results with field performance, it has been found possible to set specification limits based on these test results, with reasonable assurance of successful performance. Adequate design and proper construction practices are, of course, as essential in this type as in any other.

EVALUATING THE ADHESIVE PROPERTIES OF ASPHALT

By August Holmes[1]

Synopsis

In order to evaluate the "adhesivity" of an asphalt, that is, its resistance to being displaced from the aggregate surface in the presence of water, laboratory tests of various types have been employed. These can be grouped as partition, stripping resistance, water-displacement, briquet-soaking and abrasion-displacement tests. Of these various types, the water-displacement test appears to give the most indicative results. The use of the circular track affords a more practical means for evaluating adhesivity and details of its construction and operation have been described. According to the results obtained by the circular track, asphalt adhesivity can be increased by the use of wetting agents and the life of a paving mixture has thereby been increased up to 3.88 times that constructed with untreated asphalt. A correlation has been indicated between the results obtained on the circular track and the laboratory water-displacement tests. Although progress has been made in the knowledge on asphalt adhesivity, considerable work still remains to be done to develop a quantitative laboratory test which can be correlated with road results.

In the use of asphalts in the construction of highways, the asphalt serves as a binder for the particles of the aggregate making up the bituminized structure, the consistency of the binder varying from comparatively thin oils to the typically viscous products whose consistencies at service temperatures are most conveniently measured by penetration with a loaded needle. The asphalt must not only act effectively as a binder for the aggregate to produce a surface capable of bearing traffic but it should also maintain its binding properties under the deteriorating effects of moisture and weather. This property or ability of an asphalt to resist being displaced by water from an aggregate has been defined as its "adhesivity" in contradistinction to "adhesiveness" which is considered to be the mechanical strength by which an asphalt clings to the aggregate.

Testing for Adhesivity

As yet, to the author's knowledge, no quantitative correlation has been published between laboratory adhesivity data and results on the road. Recognizing the impracticability of duplicating in the laboratory the variation in the composition of the field waters and the various conditions to which bituminous surfaces are exposed in service, and appreciating that a laboratory adhesivity test is influenced by a number

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[1] Chemist, Standard Oil Development Co., Elizabeth, N. J.

of factors, methods that have been developed for indicating the preferential wetting of aggregates by asphalts in the presence of water appear sufficiently promising to justify discussion. All of these tests can be grouped into three main divisions: namely, partition tests, displacement tests, and abrasion-displacement tests.

Partition Test:

The partition tests are carried out along the following general line: A quantity of the mineral aggregate previously reduced to a fine particle size is placed in a container and shaken with desired quantities of water and asphalt or oil simultaneously present. Upon allowing the thoroughly agitated mixture of aggregate, water and thin asphaltic oil to settle, the water-wet aggregate will settle to the bottom of the water layer, whereas the oil-wetted material will tend to remain suspended in the oil. Depending upon conditions and the relative proportions of the materials, the preferentially oil-wetted material may finally settle into the water layer because of gravity effects. The amount of non-oil-wetted material remaining after the test is generally used as a basis for evaluating the adhesivity of the bituminous material toward the mineral aggregate under test. Our experience in comparing the various forms of the partition test with other tests has led us to the opinion that the partition procedures furnish only very rough evaluations of adhesivity.

Displacement Test:

The displacement test, in some form, is the one most frequently applied. This procedure consists, in general, in first coating the aggregate with asphaltic material and then submitting the asphalt-coated aggregate to the action of water, usually by complete immersion at some selected temperature.

Probably the best known displacement test is that of Riedel and Weber.[2] So much has already been said about this test that further comment seems superfluous beyond that the criticisms of it appear well founded.

In our work, the displacement tests employed for estimating the stripping of asphaltic materials from mineral aggregates vary somewhat with their consistency: for uncured or partially cured cutbacks, 20 hr. soaking in distilled water at room temperature; for more completely cured cutbacks or paving asphalts, 20 hr. soaking at 140 F., and a further accelerated test, boiling in distilled water for 1 to 5 min. For convenience these have been designated as stripping resistance test, water-displacement test at 140 F., and water-boiling test. The details for carrying out these several tests are as follows:

Stripping Resistance Test.—Four per cent of cutback asphalt containing at least 67 per cent of asphalt base is added to 4 to 10-mesh aggregate and mixed to complete coverage. The mixture is allowed to cure at room temperature for 1 hr. and is then placed in distilled water at room temperature for 18 to 20 hr. The percentage of aggregate surface remaining coated is recorded as the "stripping resistance." In the case of wet aggregates, the procedure is modified somewhat as follows: ¼ to ½-in. aggregate is used, the amount of cutback asphalt is increased to 6 per cent and the mixture stirred for 2 min. after which it is immersed in distilled water as above. The percentage of aggregate surface coated before immersion in water is taken as the "*coating ability*" in addition to the "*stripping resistance*" noted at the end of the test.

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[2] *Asphalt und Teer Strassenbautechnik*, Vol. 33, No. 44, November, 1933, pp. 808–812.

Water-Displacement Test at 140 F.—In the 140 F. displacement test, mineral aggregate of No. 4 to No. 10 sieve size is coated with 4 per cent of the asphalt in the form of a rapid curing cutback asphalt containing 67 per cent of asphalt. After coating, the aggregate is spread out and cured for two days at 140 F. and is then completely covered with distilled water for 18 to 20 hr. at 140 F. The aggregate still submerged in water is then cooled to room temperature for at least one hour, after which the cold water is drained off, the aggregate spread out and dried. A final evaluation of the percentage of aggregate surface still coated with asphalt is then made.

Water-Boiling Test.—The water-boiling test measures the resistance of an asphalt coating to displacement by boiling water. Strictly speaking, this test is in reality a modification of the Riedel and Weber adhesivity test using pure water, except that in the present test, the aggregate is No. 4 to No. 10 sieve size and the amount of asphalt employed is much less, amounting to 4 per cent of the aggregate. The coating of the aggregate is carried out the same as under the water-displacement test at 140 F., after which the coated aggregate is placed in a beaker, provided with a false bottom of wire screen, and covered with distilled water. The contents of the beaker are then heated to the boiling point within 6 min. and boiled for 1 min. upon which any asphalt displaced from the aggregate will either float on the water or collect on the sides of the beaker. The boiled aggregate is then cooled under running water and is then spread out, and the amount of coated surface estimated visually.

The quality of the results in the water-displacement tests depends upon the skill of the operators in estimating visually the percentage of the surface of the aggregate remaining coated with asphalts. With a little practice, different operators can rate samples within ±5 per cent. Attempts to evaluate the exposed uncoated aggregate surfaces by means of adsorption of standardized dye solutions were unsuccessful because of the apparent tendency of the asphaltic materials often to leave a thin, invisible film of resinous material over the apparently exposed mineral surface and adsorption of the dye itself by the asphalt. Some consideration will be given to the use of a reflectometer for this purpose.

In general, the water-displacement test at 140 F. and the water-boiling test give about the same results, as the following figures indicate:

Asphaltic Material	Adhesivity Value, per cent of surface coated	
	140 F. Displacement Test	Boiling Test
A	0 to 10	0 to 10
B	70 to 80	80
C	80	80 to 90
D	30 to 40	40 to 50
E	80 to 90	80

It should be mentioned, however, that sometimes the agreement of the two procedures is not so good, and in such cases, the water-boiling test generally gives the higher results. From this, one might conclude that the 140 F. water-displacement test is the more severe, due to longer time in which water is in contact with the sample.

Briquet-Soaking Test.—Another form of water-displacement test which has been investigated is that designated as the "briquet-soaking test." This consists in allowing a briquet prepared from the coated aggregate to stand in distilled water until disintegration takes place. As a matter of possible interest, the details of this test are being presented:

A briquet of 4 to 10-mesh aggregate coated with 2.5 per cent of a cutback containing 67 per cent of the asphalt under test is formed in a standard tension test mold for cement. In preparing the briquet, the cutback coated aggregate is tamped into the mold, leveled off, and then subjected to 250 lb. static pressure (71.5 psi.) for 5 min. The thickness of the mold is 1 in. After curing at 140 F. for 96 hr., the briquet is removed from the mold and kept under distilled water at room temperature until disintegration takes place. The number of days required for the breaking off of the first pieces of the briquet is taken as the "initial failure" and for the disintegration of 50 per cent of the upper perimeter of the briquet, "final failure." Although interesting, the briquet-soaking test is unsatisfactory on account of the difficulties in determining the precise point of failure, the long time required, and the poor correlation of the results with other procedures for evaluating adhesivity. During the course of the briquet-soaking tests, the interesting observation was made that in the failed briquets, the asphalt was not stripped from the stone, each loosened stone particle being completely covered with an asphalt film, as far as could be observed visually. It would appear that the briquet-soaking test includes the effect of other properties than simple adhesivity. Early results might be obtained in this procedure by the application of some form of strength measurement to the briquets after stated periods of immersion in water.

Abrasion-Displacement Test:

The abrasion-displacement tests take the form of some sort of shaking test. This consists in coating mineral aggregate with the asphalt under test, placing the coated aggregate in a can or other container, covering with distilled water, and shaking in a shaking machine until the test is considered complete. There appears to be no general agreement as to what constitutes the end point in this test. Sometimes the total aggregate surface uncoated after a definite period of shaking, or the amount of material of a certain maximum screen size stripped of asphalt after a definite shaking period, or the time required to uncover a certain percentage of aggregate surface has been considered to indicate the relative adhesivity value of the mixture. The shaking test is obviously subject to all of the errors and uncertainties involved in the water-displacement test plus those due to abrasive effects and the variations introduced by the character of the shaking at different laboratories. In fact, our experience has been to the effect that under presumably exactly the same conditions, the differences obtained at various laboratories with the same shaking test are of such magnitude as to make comparisons practically impossible.

It is, therefore, obvious that the laboratory evaluation of true adhesivity on a quantitative basis is still in an experimental state, but taking into consideration all of the defects of the various procedures, it would appear that the water-displacement tests are the best available, with preference being given to that at 140 F. This situation emphasizes the need for some fundamental research which will have for its object not only an investigation of adhesivity as a whole, but for the development of a satisfactory test or group of tests by which the adhesivity of asphalt towards mineral aggregates can be quantitatively measured. It is, of course, realized that some work has already been attempted along this line, but it appears that much more remains to be done.

CIRCULAR TRACK TEST

The value of any small laboratory test will depend upon the extent to which it indicates the results of large-scale practice. In the case of road surfaces, years may be required to correlate laboratory adhesivity values with the life of a road. In order to obtain accelerated results with road materials, the circular track has been developed by various workers and advantage has been taken of this device for evaluating the adhesivity of asphalts on a semi-practical scale, with the thought that it may be possible to work out some correlation between the small laboratory adhesivity tests and the large-scale circular track tests. If, then, a correlation can be developed between the circular track results and actual road experience, the tie-in of small laboratory adhesivity tests with road experience will be established.

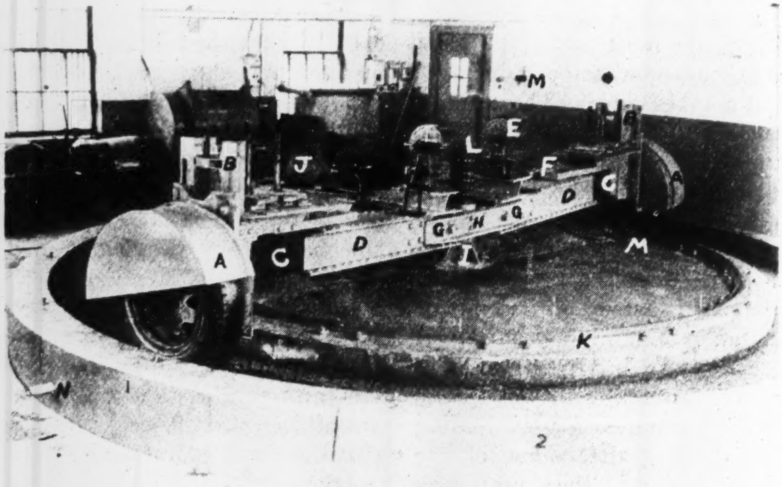

FIG. 1.—Circular Track Machine for Testing Asphalt Paving Mixtures.

A Wheel assembly.
B Height adjustment for *A*.
C Beams which are reciprocated telescopically inside.
D The main beams.
E The motors and gear reducers for reciprocating beam *C*.
F The stops and switches which control and reverse the travel of *C*.
G Heavy pins permitting vertical motion in the beams while attached to *H*, the rigid T member which is rotated around, *I*, the fixed pivot.
J The motor drive for rotating the equipment.
K Steel track on which the driving wheel runs.
L Commutator arrangement for electrical connections.
M Electrical revolutions counter.
N Drains for removing water from track.

Circular Track:

The circular track employed consists of a concrete trough, 2 ft. wide and 16 ft. in mean diameter in which hot-mixed paving mixture is placed and then compacted by the machine. The machine consists of a centrally pivoted, mechanically rotated beam supporting at its end two truck wheels equipped with heavy duty tires which have been loaded to give a dead weight of 1000 lb. on each tire (see Fig. 1). The linear speed of the wheels is 4.54 m.p.h. and they make seven passages from one side of the trough to the other each hour, to eliminate rutting. After suitable compaction followed by a curing period, the asphalt-aggregate mixture is broken down by running the wheels over the track submerged under water maintained at 90 ±1 F. The breakdown of the track is taken as the number of revolutions of the machine required to loosen

300 lb. (10 per cent) of the total asphalt-aggregate mixture laid.

This track is being used to measure from an adhesivity standpoint the relative life of paving mixtures using asphalts which have been submitted to various treatments. In order to obtain accelerated results, asphalts having a softening point of 85 F. have been generally used, although it is realized that this consistency is much lower than the asphalts normally used in road construction. The aggregate used in these tests was trap rock from a local quarry made up to the following grading:

	PER CENT
Passing 1-in. sieve, retained on $\frac{3}{4}$-in. sieve	9.0 to 10.0
Passing $\frac{3}{4}$-in. sieve, retained on $\frac{1}{2}$-in. sieve	13.5 to 14.5
Passing $\frac{1}{2}$-in. sieve, retained on No. 4 sieve	28.0 to 29.0
Passing No. 4 sieve, retained on No. 10 sieve	20.0 to 21.0
Passing No. 10 sieve, retained on No. 100 sieve	23.0 to 24.5
Passing No. 100 sieve	3.5 to 5.0

In carrying out the circular track tests, differences were early noted in the properties of stone shipments received from the same quarry at various times. Washing the aggregate was found to be necessary to reduce the deviation in track evaluation.

In an investigation carried out to determine the means to reduce the variation in circular track results, it has been found that:

(*a*) Increasing the compaction period from 2 hr. running to 10 hr. increased the apparent life of the paving mixture around 30 per cent but with a decrease in the reproducibility of the results.

(*b*) Increasing the load on the wheel from 1000 lb. to 1500 lb. during the compaction period increased the deviation in the final results.

(*c*) Increasing the curing period prior to test from 16 to 64 hr. had little effect on the apparent life of the track.

(*d*) Varying the temperature of the test between 78 F. and 90 F. showed a mean increase of 840 revolutions for each degree decrease of temperature at which the track test is made.

(*e*) Varying the consistency of the asphalt binder with the test carried out at 90 F. gave an indicated increase of track life of around 450 revolutions for each degree rise in softening point.

Comparison with information from other sources has indicated that uniformity of results is promoted by carrying out the circular track test continuously; that is, to operate 24 hr. a day until the track finally fails. The effect of extended shut-downs during the test is to increase the apparent life of the track, due possibly to a healing effect of the asphalt during the period of rest.

Based upon the above-described experience, the circular track test as now carried out in our laboratory for adhesivity determination is as follows:

The densely graded aggregate (trap rock) is mixed in a pug-type mixer with 5.5 per cent of the 85 F. softening point asphalt to be tested, having the stone at 150 to 160 F. and the asphalt at 300 to 325 F. Ten batches of mixture, 300 lb. each, are prepared and laid in two layers in the trough of the track so that a hand-tamped layer of 3 in. approximate thickness is obtained. The temperature of the track room is maintained at 85 to 90 F. during this operation. After placement of all the mixture, the temperature of the room is adjusted to 90 ± 5 F. and the mixture allowed to cool until it reaches 90 to 95 F., when compaction is begun. This is accomplished by running the track mechanism over the mixture for 1000 machine revolutions (approximately 2 hr.). After compaction, the mixture is allowed to cure at 90 ± 5 F. for 16 hr. The density of the final mixture is determined from the average thickness measurements. After the curing period, the track is flooded with a constant stream of water, maintained at a constant temperature to hold the track at 90 ± 1 F., and the machine is started. After each 500 revolutions, the water is drained off, the loosened aggregate swept up and the asphalt on the tires scraped off. The paving mixture is considered to have failed when 300 lb. cumulative dry weight of both loosened aggregate and asphalt are obtained. By close attention to all details, the track results can be made to agree within ± 15 per cent, although at times variations much less are obtained. This rather wide range of deviation in results may be due in part to the angular and splintery character of the trap rock used in these tests.

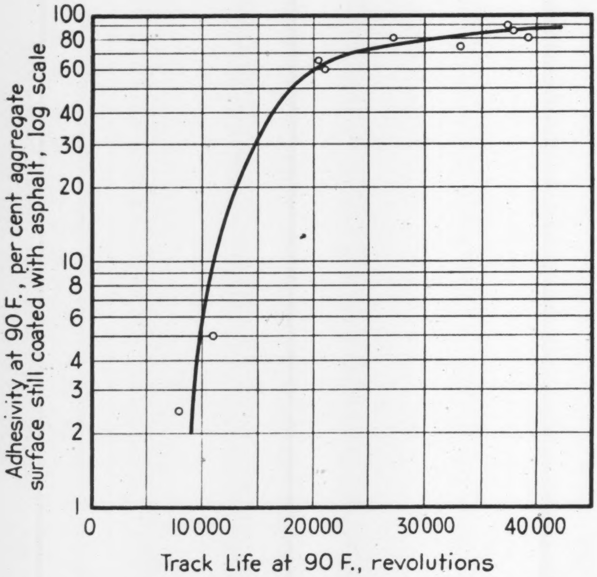

FIG. 2.—Comparison of Paving Mixture Life on Circular Track and Adhesivity Value of Asphalt.

Correlation of Track Results and Laboratory Adhesivity Tests:

Asphalt treated with various materials for improving adhesivity and used in the circular track tests were also tested for adhesivity against the same trap rock aggregate by the water-displacement and shaking test procedures. In the water-displacement test, the No. 4 to No. 10 sieve fraction of the washed aggregate was coated with the same asphalt as used in the track tests, cured and then placed for one day in water maintained at 90 F., the same temperature as the track tests. A visual estimation of the percentage of the aggregate surface still coated with asphalt was made after this exposure and termed the "adhesivity" at 90 F.

For the shaking test, the $\frac{1}{4}$ to $\frac{1}{2}$-in. portion of the track aggregate was coated with the asphalts under test. A 250-g. quantity of this mixture was placed in a 16-oz. flat type friction top can, covered with water at approximately 77 F., and then placed in a shaking machine. The mixture was shaken in a horizontal plane at the rate of 300 shakes per minute over a 6-in. stroke. Observations of the percentage of aggregate surface remaining coated were made at stated time intervals and the adhesivity expressed as the total minutes of shaking required to accomplish stripping from 50 per cent of the aggregate surface. So far the shaking test results have not given values corresponding to the improvements obtained on the track.

The data obtained on the water-displacement test, shaking test, and circular track test are summarized as follows:

Asphalt	Track Failure, 90 F., revolutions	Water-Displacement Test at 90 F., percentage of aggregate surface coated	Shaking Test, min. to 50 per cent uncoated
Untreated	11 050	5	20
Treatment A	27 400	80	105
Treatment B	20 300	60 to 70	27
Treatment C	8 000	0 to 5	....
Treatment D	33 100	70 to 80	75
Treatment E	39 400	80	43
Treatment F	38 000	80 to 90	60
Treatment G	21 000	60	60
Treatment H	38 500	90	75

In Fig. 2, the adhesivity as determined by the water-displacement test at 90 F. is plotted against the track failure in revolutions obtained at 90 F. with the same asphalts. While this curve contains no points between 5 and 60 adhesivity, the trend is nevertheless indicated. Track life increases with increased asphalt adhesivity. Above a value of 60, the improvement in track life increases greatly with small increases in asphalt adhesivity. Since the adhesivity values are based on visual estimation, it would appear that a more accurate means of obtaining such values, especially in the higher range, is necessary for evaluating in the laboratory the more effective treatments for adhesivity.

Variation in Adhesivity of Stone from the Same Source:

The track life of asphalt paving mixtures made with trap rock received *from the same quarry* during a period of 2 yr. varied over a surprisingly wide range as shown by the data presented below:

	Aug., 1937	Oct., 1937	Feb., 1938	May, 1938	Oct., 1938
pH of contact water	8.8	8.5	8.3	8.8	8.5
Track failure, revolutions:					
Untreated asphalt	3350	4 350	4 500	11 050	6 500
Treated asphalt	......	14 875	23 850	38 000	21 830
Relative life	......	3.4	5.3	3.4	3.4

These results indicate that the adhesivity characteristics of paving mixtures used in the field may vary widely due to differences in stone from the same source.

GENERAL METHODS FOR IMPROVING ADHESIVITY

Although this paper relates primarily to the measurement of the adhesivity of asphalts, some of the means which have been employed for improving their adhesivity will undoubtedly be of interest. These may be grouped as follows:

(*a*) Increasing the alkaline character of the surfaces of the acidic aggregates by either coating or treating the surface with portland cement, lime, or analogous materials.

(*b*) Modifying the surface properties of the aggregate through treatment with heavy metal salts.

(*c*) Modifying the properties of the asphalts by the addition of various activating agents such as the fatty acids, complex or organic compounds, heavy metal soaps, etc.

(*d*) Modifying both the surface properties of the aggregate by special treatments and the properties of the asphalt by the addition of wetting agents.

The efficacy of producing a thin coating of portland cement over the surface of hydrophilic aggregates for improving the adhesivity toward the subsequent coating of asphalt will depend upon the adhesivity of the asphalt to the cement and upon the adhesivity of the cement to the aggregate. The use of lime for improving the adhesivity of asphalts has been employed for many years, but it may be said that the incorporation of lime or hydrated lime into the asphalt as a filler or its application to dry aggregate does not appear to alter the true adhesivity properties of the asphalt. In the case of water-drenched aggregates, however, lime pretreatment of the aggregates appears to promote the spreading and subsequent adhesivity of asphalts containing certain adhesivity promoting agents. It may be rather surprising to point out that the lime pretreatment is very effective when applied to alkaline aggregates such as limestone.

The application of heavy metal salts to the hydrophilic aggregates for improving subsequent asphalt adhesivity appears to be quite effective, particularly when the asphalt contains some added activating agent. This procedure, however, does not appear to be particularly advantageous when the asphalt has been treated with the proper amount and kind of an effective activating agent.

As already mentioned, improved adhesivity can be obtained by the addition of an activating agent or adhesivity promoter to the asphalt. For this purpose, fatty acids, fats, complex organic compounds, and heavy metal soaps have been proposed. The present information indicates that the best results are probably obtained by the heavy metal soaps such as the aluminum, iron, and lead soaps, and certain high molecular weight organic compounds whose selection is generally a matter of trial and error.

The improvement of adhesivity by modifying both the surface properties of the aggregate by special treatments and the properties of the asphalt by the addition of wetting agents as compared with the separate procedures will generally depend upon relative costs. When using heavy metals, the most economical procedure results by their incorporation entirely in the asphalt as heavy metal soaps. For certain refractory aggregates, however, in a wet condition, it has been found that pretreatment of the aggregate and the incorporation of a heavy metal soap into the asphalt is the best means for obtaining a coating having permanent adhesivity.

It is interesting to note that some adhesivity agents appear to require the presence of moisture for their best effect, since their application to dry aggregate decreases their apparent adhesivity. In addition to the differences in treatment required when coating dry and wet aggregates, the problem of adhesivity is further complicated through the fact that agents may not have the same effectiveness when applied in hot asphalt as when they are incorporated into liquid or cutback asphalts.

Improvement in Adhesivity Obtained by Various Treatments:

The relative effectiveness, as measured by the circular track test, of various treatments for improving asphalt adhesivity are indicated by the following figures:

Treatment of Asphalt Binder	Relative Life of Track
Untreated	1.00
Fatty acid No. 1	2.48
Fatty acid No. 2	1.84
Fatty acid No. 3	2.11
Lead soap No. 1	3.43
Lead soap No. 2	2.99
Lead soap No. 3	3.56
Lead soap No. 4	1.90
Lead soap No. 5	3.88
Lead soap No. 1 in asphalt plus lead salt on aggregate	3.41

These data are interesting in showing the differences obtained with different fatty acids and different lead soaps. The maximum improvement obtained corresponds to a relative track life of 3.88 times that of the untreated asphalt.

SUMMARY

In the investigation of means for improving the adhesivity properties of asphalts, various small-scale laboratory procedures have been developed of which the water-displacement test at 140 F. appears to be the best on the basis of present information. In order to obtain results of a more practical character, circular track tests have been made and a standard procedure of test developed. From the circular track test it appears that by the use of suitable wetting agents in the asphalt, relative improvement in pavement life up to 3.88 times that of untreated asphalt can be obtained. An approximate correlation between the water-displacement test and circular track test has been indicated which, however, requires further data for its better establishment. The treatment of the asphalt to obtain successful coating and subsequent permanence of the coating from an adhesivity standpoint varies somewhat depending upon whether the aggregate is in a dry or wet condition.

There still remains considerable work to be done to develop a small-scale laboratory adhesivity test of a quantitative nature and which can be correlated with road results.

The present work has been limited to the use of petroleum asphalts used straight and in the form of cutback asphalt, but investigations are proceeding in other laboratories seeking to improve the adhesivities of asphalt emulsions through various means.

DISCUSSION

Mr. C. Mack[1] *(presented in written form)*.—Mr. Holmes is to be congratulated upon his paper describing various methods for the evaluation of the adhesive properties of asphalt. Such methods are becoming engineering tools for the determination of the resistance of bituminous pavements against the action of water.

The property of an asphalt to resist displacement by water from an aggregate is called "adhesivity" by the author. In physical terms, "adhesivity" is equivalent to the energy which is directed against the interfacial energies in a system consisting of aggregate, asphalt, and water. This energy is equal to:

$$E = S_{\text{aggregate/asphalt}} - S_{\text{aggregate/water}} - S_{\text{asphalt/water}}$$

where S denotes the interfacial energy, and the suffixes denote the interfaces.

If the energy E is zero or positive, the water will displace the asphalt from the aggregate. This relationship does not take the time of displacement into consideration, and the rate of displacement is mainly a function of the viscosity of the asphalt. Therefore, the methods described measure "adhesivity" plus binder effect of the asphalt. This is especially borne out by the results obtained on the circular track with one asphalt at various temperatures and with asphalts of various softening points at 90 F.

The different laboratory methods for the evaluation of the adhesive properties of asphalts have the drawback that the interpretation of the results depends upon visual examination. The writer agrees with Mr. Holmes with regard to the difficulties encountered when attempts are made to place the laboratory methods on a quantitative basis. In this regard the circular track is a valuable testing device which approaches conditions on the road and yields results that are in good agreement.

The improvement in adhesion obtained by the addition of agents to the asphalt or by pretreatment of the aggregate are very interesting, and are a valuable contribution, leading finally to better and cheaper bituminous pavements.

Mr. W. H. Herschel.[2]—I should like to ask why a visual estimation was made of the percentage of surface covered. Could it not be estimated from the weight of the coating material?

Mr. August Holmes.[3]—Not necessarily, because sometimes the asphalt merely collects upon the rock in little "gobs" or droplets, and is not completely removed from the rock. Some may float off, but they generally do not. It is necessary to estimate the exposed surface according to the eye. I might mention that we have tried to evaluate the exposed surface through comparative methods by using the absorptive power of wet aggregate when immersed in a standard dye solution. In this we ran into difficulties because, although asphalt is sometimes apparently displaced from the rock surface, a thin resinous film very often occurs which prevents the absorption of the dye. After running a large number of tests, we have concluded that a visual estimation is the best that can be done.

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[1] Research Chemist, Technical and Research Division, Imperial Oil Limited, Sarnia, Ont., Canada.

[2] Associate Materials Engineer, National Bureau of Standards, Washington, D. C.

[3] Chemist, Standard Oil Development Co., Elizabeth, N. J.

MR. A. J. KRAEMER.[4]—The last statement prompts a question. Is there any relationship between the resin content of asphalt and the adhesivity?

MR. HOLMES.—We have never directly taken up the effect of resin content. I might answer it indirectly: We have taken asphalts of the same softening point from different sources, which would vary in their resin content from a relatively small to a relatively large amount, and have found that they all yielded practically the same results lying within experimental error or within a slight deviation from it.

MR. KRAEMER.—Despite the difference in the resin content, is the adhesivity about the same?

MR. HOLMES.—Yes, about the same for untreated asphalts from different sources.

MR. A. W. DOW.[5]—Referring to Mr. Herschel's comments, we are trying in the Colprovia laboratory to separate the coated from the uncoated aggregates, after the washoff test, by the use of heavy solutions. The uncoated portion of the aggregate sinks while the coated portion floats. Of course, this method is not entirely satisfactory because portions of the aggregate may be only partially stripped so that some of the material sinks while the rest floats, but even so it is better than guessing from a visual examination.

In Mr. Holmes' paper there is a point to which I wish to call attention: namely, in several of the methods which he describes only that portion of the aggregate between 4 and 10 mesh is examined. The results obtained from such tests are valueless unless, of course, the aggregate is to consist of only 4- to 10-mesh material. If such tests are to be of value, the entire aggregate as used in the pavement or roadway, from coarse to fine, must be tested together. In many cases, tests on the aggregate retained on the No. 10 sieve will give contrary results to tests on the aggregate passing the No. 10 sieve. For example, a paving mixture made with straight Ottawa sand graded from No. 10 to passing No. 200 sieve will not stand up satisfactorily in the washoff test. If the 80- and 200-mesh silica dust is replaced by certain limestone dusts and 0.5 per cent of hydrate of lime is added, a mixture is obtained that is most satisfactory. If the Ottawa sand is washed with dilute hydrochloric acid, mixtures will stand the washoff test without the necessity of replacing the fine 80- and 200-mesh silica filler. This is evidence that the pH value of the aggregate, or its alkalinity and acidity, is not a governing factor in this phenomena.

We have found the washoff test invaluable in the selection of aggregates and in the improvement of aggregates already in use.

MR. J. S. MILLER.[6]—Mr. Holmes refers to using materials of 85 F. softening point. This may or may not indicate materials of about hot-road-oil consistency. Can Mr. Holmes give us results when using harder materials, such as asphalt cements suitable for sheet asphalt or asphaltic concrete of say about 120 F. softening point, or perhaps slightly lower of about 110 F., such as might be used in stone mixtures intended for laying cold?

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[4] Senior Refinery Engineer, U. S. Bureau of Mines, Washington, D. C.

[5] Consulting Paving Engineer, A. W. Dow, Inc., New York City.

[6] Technical Adviser, Barber Asphalt Corp., Barber, N. J.

MR. HOLMES.—Our track went through a series of tests with asphalts of increasing softening point, and as far as our conditions were concerned the limit was found to be about heavy flux. When using binder "C," the operations of the track were erratic, and we were unable to get results of any value.

MR. MILLER.—In other words, the asphalts reported upon are probably liquid bituminous products rather than semi-solid ones and are similar to hot road oils rather than asphalt cements?

MR. HOLMES.—Yes.

A MEMBER.—Mr. Dow's comments suggest the thought that the difference between the behavior when silica dust was present and when limestone dust replaced the silica dust is the probability that calcium soaps are formed of the naturally occurring petroleum acids in the asphalt, which would tend to increase the adhesiveness of the asphalt. Practically all asphalts as far as we know do contain some natural occurring acids, which under heat would react with the limestone.

MR. HOLMES.—In reference to some of the questions on dust, we found out early in the operation of the track that it was impossible to obtain consistent results when the stone was in a dusty condition, and that we had to wash the aggregate in order to obtain uniformity. One of our greatest troubles in operating the track has been to obtain consistent results within reasonable limits of the deviations of the data. There is a recent German article,[7] however, which states that the presence of dust on the aggregate promoted adhesivity, so that question appears to be still unsettled.

As to the question of the alkalinity of aggregates, in the early work with which I am familiar, the alkalinity of the aggregate was supposed to have a great influence, but after several years now we have found that that does not furnish any reliable indication. By the alkalinity of an aggregate we mean the pH value of the contact of water. The dust we have been using in our track mixtures is from the aggregate employed. This was intentionally done since it was desired to have only one variety of aggregate present and thereby avoid complications which might be attributable to admixtures of other materials. We admit that this differs somewhat from occasional paving practice. We have found by cut-and-try methods that to obtain adhesivity measurements in the laboratory we should not use smaller than 10-mesh material. By the introduction of fine filler the viscosity of the asphaltic binder is increased, which will tend to make the displacement of the asphalt a little more difficult. This is a practical consideration which we realize.

MR. DOW.—We find a great difference in aggregates. In some cases the fines naturally associated with the aggregate are detrimental and have to be replaced, while in other cases, the fines are most beneficial. We have a most remarkable sand at Bedford Hills, N. Y. The 200-mesh material, which is entirely siliceous, is most hydrophilic and its presence in mixtures adds greatly to their resistance to water action.

I hope my remarks have indicated the great necessity for testing asphalt mixtures containing the entire aggregate from the coarsest to the finest, if the results are to be of any value as guides to practical work.

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[7] H. Mallison and H. Schmidt, *Asphalt und Teer Strassenbautechnik*, Vol. 31, No. 4, January 25, 1939, pp. 51-54.

SOME FACTORS AFFECTING THE THERMAL SUSCEPTIBILITY OF ASPHALTIC PAVING MIXTURES

By Roland Vokac[1]

Synopsis

The compressive strength of asphalt mixtures at various temperatures is used to evaluate a mixture susceptibility index. Thermal susceptibility is found to vary with mixture composition, kind of asphalt cement used in the mixture, and temperature of the mixture. It is shown in comparable mixtures that the thermal susceptibility of the mixture varies according to the thermal susceptibility of the asphalt cement.

Considerable information is available[2] on the temperature-consistency relationships of asphalt cements. However, there is scant information available regarding the change in strength or stability of asphalt paving mixtures with change in temperature. It is the purpose of this paper to present some data on this subject as they were recently obtained in our laboratory.

The compression test was used as the measure of strength or stability because of the correlation it has shown with service performance of mixtures.[3] All compressive strength data given in this paper were obtained on cylindrical briquets 2 in. in diameter by 1 in. high. The mixtures were made in a small laboratory mixer having an elliptical bottom mixing bowl in which the ingredients are mixed by a paddle or beater traveling with a planetary motion.[4] Mixtures made in this mixer have been checked against those made in our laboratory pug mill, which in turn have been found equivalent to those made in large-scale mixers in an asphalt plant. The mixtures were made at 325 F. and the briquets at 305 to 315 F. in molds which were at 310 F. The proper weight of mix for each briquet was compressed in its mold in a Carver laboratory press between two opposed plungers under a load of 5000 psi. maintained for 10 sec. and then released. The briquets were chilled in the mold in water before removal.

The compressive strengths were obtained the day following manufacture and briqueting of the mixtures. They were tested after 1 hr. in a water bath maintained within ± 1 per cent of 34, 77 or 140 F. The testing machine used was a hydraulic Baldwin-Southwark compression tester[5] equipped so that the rate of compression could be accurately controlled at any speed within rather wide limits. Each briquet was tested at the rate of 0.05 in. per minute.

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[1] Chief of Paving Research, Technical Bureau, Barber Asphalt Corp., Barber, N. J.

[2] H. E. Schweyer, C. E. Coombs and R. N. Traxler, "The Susceptibility of Asphalts to Temperature Change," *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part II, p. 531 (1936). (These authors have included many valuable references.)

[3] Roland Vokac, "Correlation of Physical Tests with the Service Behavior of Asphaltic Mixtures, I and II," *Proceedings*, Assn. Asphalt Paving Technologists, January and December, 1937, respectively.

[4] Kitchenaid Mixer, Model G, Hobart Manufacturing Co., New York City.

[5] Roland Vokac, "Compression Testing of Asphalt Paving Mixtures," *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part II, p. 552 (1936).

Each value of the compressive strength given is the average compressive strength of three briquets of the same mixture. In every case the average deviation is less than ±2.5 per cent.

TABLE I.—INFLUENCE OF MIXTURE COMPOSITION ON TEMPERATURE SUSCEPTIBILITY OF MIXTURE STRENGTH.

Mix	Mixture					Temperature Susceptibility Characteristics				
	Composition, per cent		Character			Compressive Strength, psi.			$p = ae^{bT} + c$	Mixture Susceptibility Index at 77 F.
	Oil Asphalt Cement	Filler	Bitumen	Filler	Voids in Mix, per cent	34 F.	77 F.	140 F.		
No. 1.....	8.0	12.1	Low	Normal	8.2 (High)	1925	698	80	$p = 4256e^{-0.0212T} - 142$	2.56
No. 2.....	9.6	11.9	Normal	Normal	4.5 (Normal)	1895	655	75	$p = 4574e^{-0.0240T} - 86$	2.72
No. 3.....	11.2	11.7	High	Normal	1.4 (Low)	2200	600	73	$p = 5959e^{-0.0292T} - 23$	3.03
No. 4.....	9.6	5.0	Normal	Low	8.0 (High)	1650	510	39	$p = 4030e^{-0.0248T} - 84$	2.89
No. 5.....	9.6	18.3	Normal	High	1.5 (Low)	2360	830	139	$p = 5615e^{-0.0244T} - 44$	2.57

NOTE 1.—Asphalt cement is 50 penetration Venezuelan vacuum refined. Melting point (ring and ball) = 124 F. Ductility at 77 F. = 150 cm.+.

NOTE 2.—The sand has the following gradation:

	Per cent by weight
Retained on No. 10 sieve	0.0
Passing No. 10, retained on No. 40 sieve	20.5
Passing No. 40, retained on No. 80 sieve	56.2
Passing No. 80, retained on No. 200 sieve	20.2
Passing No. 200 sieve	3.1
	100.0

NOTE 3.—The filler is limestone dust having 95 per cent passing the No. 200 sieve.

TABLE II.—TEMPERATURE SUSCEPTIBILITY OF MIXTURES MADE WITH VARIOUS ASPHALT CEMENTS.

Mix	Asphalt Cement Used in Mix	Asphalt Cement				Compressive Strength, psi.			$p = ae^{bT} + c$	Mixture Susceptibility Index at 77 F.	Compressive Strength at Ring-and-Ball Softening Point Temperature, psi.
		Penetration at 77 F.	Ring-and-Ball Softening Point	Ductility at 77 F.	A.V.I.[b]	34 F.	77 F.	140 F.			
No. 6....	California[a]	60	118	150+	13.7	2175	570	68	$p = 6488e^{-0.0314T} - 20$	3.25	140
No. 7....	Mid-Continent[a]	39	130	150+	12.1	2795	850	113	$p = 6970e^{-0.0265T} - 58$	2.83	165
No. 8....	Venezuelan[a]	51	124	150+	11.7	2190	720	102	$p = 5200e^{-0.0246T} - 64$	2.68	181
No. 9....	Venezuelan	72	120	150+	11.6	1730	590	86	$p = 3995e^{-0.0236T} - 61$	2.61	174
No. 10....	Mexican[a]	54	133	72	11.4	2050	750	132	$p = 4540e^{-0.0223T} - 68$	2.43	165
No. 11....	Trinidad	49	127	60	11.1	2065	770	145	$p = 4135e^{-0.0204T} - 93$	2.29	216

[a] These asphalts were used in presentation of "Viscosity Index," R. N. Traxler, and H. E. Schweyer, "Rheological Properties of Asphalts III. A Viscosity Index," *Physics*, Vol. 7, February 1936, pp. 67–72.

[b] A.V.I. (asphalt viscosity index) has been converted from Centigrade to Fahrenheit scale of temperature.

NOTE.—The percentage bitumen by weight is constant at 9.8 per cent for all the above mixtures. The sand-filler ratio is also constant at 5/1. The sand grading is the same as that used in the mixtures for Table I.

DATA

Data have been obtained showing the effects of mixture composition and the use of various typical asphalt cements in mixtures. These data, which include mixture compositions, identification of the ingredients and characteristics of the mixtures are given in Tables I and II.

Data showing the influence of mixture composition on the susceptibility of compressive strength to change in temperature are shown in Table I, and data for the susceptibility of comparable mixtures containing various types of asphalt cements are shown in Table II.

Temperature Susceptibility Measurement:

We have used the A. V. I.[2] "asphalt viscosity index" developed in our laboratories to evaluate the viscosity-temperature susceptibility of the asphalt cements:

$$\text{A. V. I.} = 100\ (10^{a} - 1)$$
$$= 100(\eta_c/\eta_d)^{1/(T_c - T_d)} - 1 \ldots (1)$$

where η_c and η_d are the viscosities in poises of the asphalt cement at temperatures T_c and T_d (in degrees Centigrade), respectively.

This is derived from the viscosity-temperature equation:

$$\log \eta = a\,T + \log b \ldots\ldots (2)$$

where η is the viscosity in poises of the asphalt cement at temperature T in degrees Centigrade. a and b are constants.

The A. V. I. evaluates the percentage change in viscosity of an asphalt cement for an increment of one degree rise in temperature.

The A. V. I. is a function of the slope, a, of the line represented by Eq. 2. Therefore, the relative susceptibility of viscosity to temperature can be referred to the slope, since from Eq. 2,

$$100\,\frac{d\eta/dT}{\eta_0} = (a \log_e 10)100$$
$$= 100a' \ldots\ldots\ldots\ldots\ldots (3)$$

where $a' = a \log 10$.

Equation 3 states that the percentage rate of change in viscosity with respect to temperature is a constant. This differs from the A. V. I., Eq. 1, only by the fact that the A. V. I. represents the percentage change in viscosity for an increment of 1 deg. rise in temperature. The expression (a $\log_e$ 10) 100, from Eq. 3, would give equally good comparative data regarding asphalt susceptibility as that obtained from the A. V. I., but its meaning is perhaps more difficult to grasp than that of the A. V. I.

The data obtained for this paper show that the relation of mixture strength susceptibility to change in temperature is amenable to the same analysis. The only point of difference is the presence of a third constant, as shown in Eq. 4.

$$\log_e (p - c) = \log_e a + b\,T \ldots (4)$$

where p is the compressive strength in pounds per square inch, T is the temperature (in degrees Fahrenheit), and a, b, and c are constants.

The percentage rate of change of compressive strength with respect to temperature is a function of the compressive strength, since

$$100\left(\frac{dp/dT}{p}\right) = 100b\left(1 - \frac{c}{p}\right) \ldots (5)$$

In order to evaluate the constants in Eq. 4, it is only necessary to know the compressive strength at any three temperatures. A simpler method, however, results when the three compressive strengths are determined at three equally spaced temperatures so that p_1 is measured at T_1, p_2 at T_2, and p_3 at $T_3 = \frac{T_1 + T_2}{2}$. The constant c may then be easily evaluated by Eq. 6, as

$$c = \frac{p_1 p_2 - p_3^{2}}{p_1 + p_2 - 2p_3} \ldots\ldots (6)$$

The values of c, p, and T are then substituted in Eq. 4 for evaluation of a and b. These constants may also be determined graphically by plotting log (p − c) against T.

The percentage rate of change in mixes is a function of compressive strength at any given temperature, and in order to compare with the A. V. I. data pertaining to the asphalts it should be evaluated within the range of temperatures selected for the A. V. I.

The temperature range for the A. V. I. of various asphalts given in Table II is from 15 to 35 C. (59 to 95 F.) or for an average temperature of 25 C. (77 F.). The mixture susceptibility indices (M.S.I.) given in the tables are calculated by Eq. 5 for the values of p at 77 F. It may be pointed out that at low temperatures the M.S.I. (Eq. 5) approaches the value of 100 b (100 times slope) since p becomes very large with respect to the constant c. At high temperatures, however, where p is small, the M.S.I. becomes very large (c has negative values). Supplementary data showing the M.S.I. at various temperatures are given in Table III.

TABLE III.—MIXTURE SUSCEPTIBILITY INDEX (M.S.I.) AT VARIOUS TEMPERATURES.

(*a*) MIXTURES ILLUSTRATING EFFECT OF MIXTURE COMPOSITION.

Mixture Composition, per cent		100 b	M.S.I. at Temperatures Given		
Oil Asphalt Cement	Filler		34 F.	77 F.	140 F.
8.0	12.1	2.12	2.28	2.56	6.15
9.6	11.9	2.40	2.51	2.72	5.16
11.2	11.7	2.92	2.95	3.03	3.94
9.6	5.0	2.48	2.61	2.89	7.84
9.6	18.3	2.44	2.48	2.57	3.21

(*b*) MIXTURES MADE WITH VARIOUS ASPHALTS.

Asphalt Cement	Penetration	Ring-and-Ball Softening Point	100 b	M.S.I. at Temperatures Given			
				34 F.	77 F.	Ring-and-Ball	140 F.
California	60	118	3.14	3.16	3.25	3.60	4.06
Mid-Continent	39	130	2.65	2.71	2.83	3.59	4.01
Venezuelan	51	124	2.46	2.53	2.68	3.33	4.00
Venezuelan	72	120	2.36	2.44	2.61	3.19	4.03
Mexican	54	133	2.23	2.31	2.43	3.15	3.38
Trinidad	49	127	2.04	2.13	2.29	2.92	3.35

Effect of Mixture Composition:

In Table I a normal mixture composition, found satisfactory for the sand, filler, and asphalt cement used, has been modified successively in two ways. First, the bitumen is varied from lean to rich proportions, and, secondly, the filler has been varied from a deficient quantity to an excess. The actual data at three temperatures, the derived equation, and the M.S.I. are given for each.

It will be observed that increasing the bitumen content results in increasing values of the M.S.I. at 77 F., while increasing the filler content results in decreasing values of the M.S.I. at 77 F. Referring to Table III, part (*a*), however, shows that at low temperature the effect of variation in the bitumen content is by far more pronounced than the change due to variation of the filler. The M.S.I. at low temperature is primarily a function of the bitumen content while at normal and high temperatures it is affected both by bitumen and filler content.

Effects Due to Various Asphalt Cements:

In Table II are the data for mixtures containing different asphalt cements. It will be noted that the A.V.I. is not dependent upon penetration, softening point, or ductility of the asphalt cements used. The mixtures have been arranged in decreasing order of the A.V.I. of the asphalt cements used, and the M.S.I. in the next to the last column follows the same order of susceptibilities. It appears, then, that the susceptibility of mixtures is dependent upon the susceptibility of the asphalt cements used.

The two Venezuelan asphalt cements of 51 and 72 penetration have been included to illustrate the effect of consistency of the asphalt cement from a given source and method of processing on its A.V.I. and on the M.S.I. of the mixtures in which they are used. The harder Venezuelan asphalt of 51 penetration has only a slightly higher A.V.I. than the softer 72 penetration Venezuelan. The M.S.I. of the corresponding mixtures show the same relationship. The difference between the A.V.I. and M.S.I. of the two Venezuelan asphalts is not as great as that between the 51 penetration Venezuelan and 54 penetration Mexican. It follows, therefore, that using a softer asphalt from a given source and method of processing may result in lowering the M.S.I. somewhat. However, inspection of the data shows that the M.S.I. as well as A.V.I. is more markedly influenced by the source and method of processing than by the consistency (penetration) at a given temperature.

Compressive strengths at the ring-and-ball softening point temperature are included in the last column of Table II. These data show that the softening point of the asphalt cement has no direct bearing upon the compressive strength of a mixture. A mixture made with an asphalt cement having a low softening point is not necessarily weak or unstable at an elevated temperature.

In Table III, part (*b*), the M.S.I. at various temperatures shows the same general order but vary with respect to each other in degree. The M.S.I. of the first four mixtures are nearly alike at 140 F. though markedly different at lower temperatures.

CONCLUSIONS

Practical conclusions which the data imply may be summarized as follows:

1. The susceptibility of a mixture increases with the bitumen content at temperatures in the neighborhood of 77 F. and lower. At temperatures approaching 140 F., the order of susceptibility is reversed.
2. Although, in general, additional filler decreases the susceptibility of a mixture made with a given asphalt, this effect is less evident at low temperatures.
3. The source and method of processing an asphalt markedly influences the susceptibility of a mixture in which it is used.
4. Using a soft asphalt in place of a harder one from a given source and process may decrease the M.S.I. at temperatures up to 77 F. or higher; but the soft asphalt may result in greater susceptibility at temperatures about 140 F.
5. The ring-and-ball softening point of a paving asphalt cement apparently has no direct influence on the strength or the M.S.I. at the softening point temperature.
6. In comparable mixture compositions, the M.S.I. at 77 F. varies according to the A.V.I. of the asphalt cements used.

We may logically infer, therefore, that in order to obtain mixtures having similar physical characteristics such as susceptibility, strength, voids, etc., using asphalts from different sources, the mixtures must be proportioned individually to suit the unique characteristics of each asphalt.

DISCUSSION

Mr. T. W. Thomas[1] (*presented in written form*).—Mr. Vokac's paper contributes much toward the attainment of a more fundamental understanding of asphalt pavement behavior. The increase in compressive strength of mixtures with decrease in temperature may be expected to hold over wide limits in temperature. However, some work performed in our laboratory would indicate that tensile strength may increase to a maximum and then become less with decreasing temperature. The pronounced effect of slight eccentricities in loading upon the tensile strength of brittle materials may easily explain this difference between compressive and tensile strength.

Referring to conclusion 5 of the paper, one would not expect to find a relation between M.S.I. and softening point temperature since all of the asphalts could have been produced to the same softening point. However, Table II indicates reasonably good agreement between the compressive strengths of the various mixtures at their respective softening point temperatures. Perhaps the variations shown may be accounted for by the degree of departure of the various asphalts from viscous flow or by differences in their rate of age hardening. The California asphalt, lowest in mixture compressive strength at the softening point temperature, is perhaps the most truly liquid material and has the smallest rate of age hardening.

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[1] Senior Engineer, Minnesota State Highway Dept., University of Minnesota, Minneapolis, Minn.

THE DETERMINATION OF ORGANIC SULFUR IN GASES BY THE CATALYTIC HYDROLYSIS METHOD

By Lawrence T. Jilk[1]

Synopsis

A new analytical method for determining organic sulfur in gas mixtures is described. The method avoids the use of a flame or any exposed hot body and depends on the possibility of converting the organic sulfur compounds to hydrogen sulfide in contact with activated alumina at an elevated temperature. Any oxygen and hydrogen sulfide which may be present in the gas are first removed by an acidic chromous chloride solution and by an alkaline cadmium chloride solution, respectively. The gas is then passed through a bed of activated alumina held at 500 C., after which the hydrogen sulfide formed from the organic sulfur compounds is absorbed in a cadmium chloride solution and determined by iodimetric titration.

The method and apparatus are described in detail. A description of the method of preparation of the acidic chromous chloride solutions is included. All refinements in technique and necessary precautions to be observed are given. The method is accurate to within 5 per cent when the gas contains 0.5 to 15.0 grains of organic sulfur per 100 cu. ft., and to within 20 per cent when the gas contains 0.002 to 0.05 grains of organic sulfur per 100 cu. ft. The presence of thiophene or of iron carbonyl in the gas lead to low results.

In 1929 the use of the burner method for the determination of organic sulfur in various plant gas mixtures at the Belle Works of E. I. du Pont de Nemours and Co. was discontinued because of the accompanying fire hazard in many plant areas. A new analytical procedure was developed, which avoided the use of a flame or any exposed hot bodies, based on the possibility of converting the organic sulfur to hydrogen sulfide in contact with activated alumina as a catalyst. Hundreds of analyses have since been made by this method. The gas to be analyzed is first freed from oxygen by means of an acidic chromous chloride solution, and from hydrogen sulfide by means of a slightly alkaline cadmium chloride solution. The gas then is passed through a bed of activated alumina at 500 C., after which the hydrogen sulfide formed from the organic sulfur compounds is absorbed in a cadmium chloride solution and determined by iodimetric titration.

Figure 1 gives a diagrammatic sketch of the apparatus and Fig. 2 shows an analyzer ready for use.

Accuracy of Method:

Variations in duplicate analyses on a gas containing 0.5 to 15.0 grains of organic sulfur (presumably largely carbon disulfide and carbon oxysulfide) per 100 cu. ft. (0 C., 760 mm., dry) will average about 3 per cent and will not exceed 5 per cent, and on a gas containing 0.002 to 0.05 grains of organic sulfur per 100 cu. ft. the variation will not exceed 20 per cent. These percentage figures also approximate the absolute accuracy of the method.

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[1] Chemical Engineer, Ammonia Dept., E. I. du Pont de Nemours and Co., Charleston, W. Va.

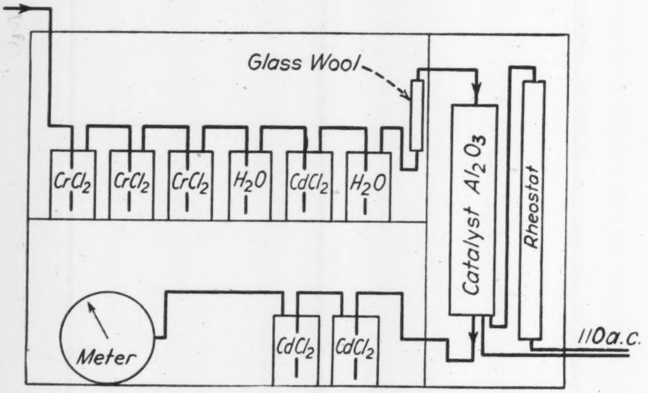
Glass Wool
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FIG. 1.—Diagrammatic Sketch of the Analyzer.

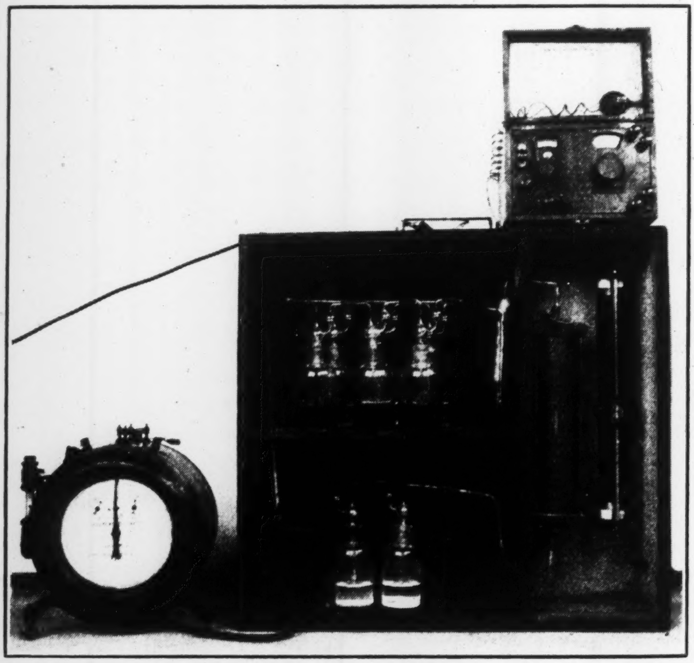

FIG. 2.—Analyzer Ready for Use.

Time Required:

The method requires only two or three hours for gas containing 5 grains of organic sulfur per 100 cu. ft., but requires about two days for gas containing only 0.005 grains of organic sulfur per 100 cu. ft.

Conversion of Organic Sulfur to Hydrogen Sulfide:

The main sulfur-containing compounds present in coke water gas, other than hydrogen sulfide, are carbon disulfide and carbon oxysulfide. The mechanism by which these compounds are converted to hydrogen sulfide in contact with an alumina catalyst is believed to be hydrolysis. The following equations probably represent the reactions taking place:

$$CS_2 + 2\,H_2O \rightarrow CO_2 + 2\,H_2S$$

$$COS + H_2O \rightarrow CO_2 + H_2S$$

Using equilibrium constants for these reactions derived from thermodynamic relationships it has been calculated that at 500 C. in a gas free of hydrogen sulfide and saturated with water vapor at 20 C. the organic sulfur compounds will be practically quantitatively converted to hydrogen sulfide even if the percentage of carbon dioxide in the gas is as high as 25 per cent. Experimentally, hydrolysis has been found to be practically complete for gases containing from 0.002 to 15.0 grains of organic sulfur per 100 cu. ft.

Action of Catalyst:

Regarding the mode of action of the catalyst it has been reported[2] that the mechanism consists in a sulfiding of the catalyst followed by immediate hydrolysis of the sulfide yielding hydrogen sulfide and the regenerated oxide. Activated alumina also is known to adsorb carbon disulfide, carbon oxysulfide, and water vapor by what is supposedly surface adsorption. This fact will cause the method to give erroneous results unless certain precautions, discussed in the method, are closely adhered to.

Effect on Thiophene:

Thiophene has been found to be only partially converted to hydrogen sulfide by alumina at 500 C. Thiophene is presumably not present in appreciable quantity in gas derived from coke. No study has been made of the action in this analyzer of organic sulfur compounds other than the three already mentioned.

APPARATUS

General Assembly:

The equipment is housed in a wooden frame approximately 25 in. high, 27 in. long, and 6½ in. wide, boarded shut on one side and open on the other (Fig. 2). A vertical partition is placed 7½ in. from one end, and the catalyst tube and rheostat occupy the section there formed. In the other larger section a shelf is placed 12 in. from the bottom on which the six absorption bottles constituting the preliminary scrubbing train are placed. These six bottles are conveniently placed in two parallel groups of three each, a piece of glass tubing connecting the last of the first trio with the first of the second. On the lower shelf or floor are placed the two bottles in which the hydrogen sulfide to be titrated is absorbed.

Design of the Electric Heater:

Two pieces of transite board 3½ in. square and ⅜ in. thick constitute the top and bottom frame of the furnace. A 1⅛-in. diameter hole is drilled in the center of each piece and ground out so that the catalyst tube may pass through freely. The core of the heater is an alundum electric furnace core, bore 1¼ in., length 12 in., pitch 1/9 in., which is fitted into a countersunk depression concentric with the holes drilled for the catalyst tube in each of the transite end pieces. The core is wound with 36 ft.

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[2] B. Neumann and E. Altman, "The Catalytic Reaction Between Carbon Disulfide and Steam," *Zeitschrift für Elektrochemie*, Vol. 37, p. 173 (1931).

of No. 24 B. & S. gage nichrome wire. Two small holes are drilled into the transite end pieces for the nichrome wire terminals, each of which fastens into one end of a small copper wire connector. A thin sheet iron cylinder $3\frac{1}{2}$ in. in diameter and 12 in. long is used to hold the insulating material in place. Kieselguhr is used as the insulating material, the annular space between the core and the iron cylinder being completely filled. The entire assembly is then fastened together by four rods threaded on each end which pass through holes drilled in the four corners of the transite end pieces and are pulled tight by eight nuts.

A 28-ohm cylinder-type variable resistance of 5-amp. capacity is placed in series with the heater and the terminals are connected to an extension cord equipped so that it can be plugged into a 110 volt a.c. line. The sliding contacts of this resistance should be kept clean in order to avoid sparking when changes of setting are made.

Absorption Bottles:

All bottles used in scrubbing the gas and in absorbing the hydrogen sulfide are 250 ml. Drechsel wash bottles with interchangeable ground-glass stoppers. The height of the inlet and exit tubes of all of these bottles should be the same so that rubber connections between bottles may be made as nearly butt joints as possible. It is good practice to blow out the submerged end of the inlet tube of these bottles into a small sphere and to make three or four small holes in this sphere. This will divide the gas stream into smaller bubbles and lead to better contact between gas and solution. No stop-cock grease is used on the ground-glass stoppers since organic sulfur compounds given off by, or absorbed by the grease might lead to erroneous results. This applies to all ground-glass joints in the assembly.

Catalyst Tube:

The catalyst tube consists of a 12-in. length of $1\frac{1}{8}$ in. outside diameter Pyrex tubing to each end of which is sealed one member of a ground-glass joint. It has been found that the temperature can be satisfactorily controlled by means of a thermocouple placed between the alundum core and the glass catalyst tube. The space at the top of the heater between the core and the glass tube should be packed with loose asbestos to eliminate drafts up around the catalyst tube.

The last Drechsel bottle in the scrubbing train is connected to the catalyst tube through a liquid spray trap which consists simply of a 5-in. length of Pyrex tubing $\frac{7}{8}$ in. outside diameter filled with glass wool and provided with a ground-glass joint to fit the inlet end of the catalyst tube. Connection between the bottom of the catalyst tube and the first of the hydrogen sulfide absorption bottles is made through a suitable length of glass tubing to each end of which is sealed one member of a ground-glass joint, the first of the pair of hydrogen sulfide absorption bottles also having a ground-glass joint sealed to it. This glass connecting piece runs through a hole drilled in the vertical partition at a suitable height from the bottom of the box.

OPERATION OF THE ANALYZER

Technique Required:

Good results may be obtained by the use of this method only when care is taken to follow directions explicitly, as might be expected in view of the small quantity of material being analyzed for. Experience has shown that apparently trivial variations in the method may lead to erroneous results.

Removal of Oxygen:

If any oxygen contained in the gas to be analyzed is allowed to enter the catalyst tube the sulfur found will be too low, probably because of the formation of elemental sulfur or sulfur dioxide. The oxygen is removed by passing the gas through three Drechsel wash bottles each containing 100 ml. of acidic chromous chloride solution. This solution is prepared by reducing a chromic chloride solution in a modified Jones reductor by means of amalgamated zinc.[3] The amalgamated zinc is prepared by stirring 480 g. of pure granulated zinc for 30 sec. with 200 ml. of 3 *N* hydrochloric acid and then adding a solution consisting of 10 ml. of saturated mercuric chloride solution and 190 ml. of water and stirring for an additional 3 min. The evolution of hydrogen will practically cease on addition of the mercuric chloride solution. The amalgamated zinc is then carefully washed with distilled water and placed in the reductor as shown in Fig. 3.

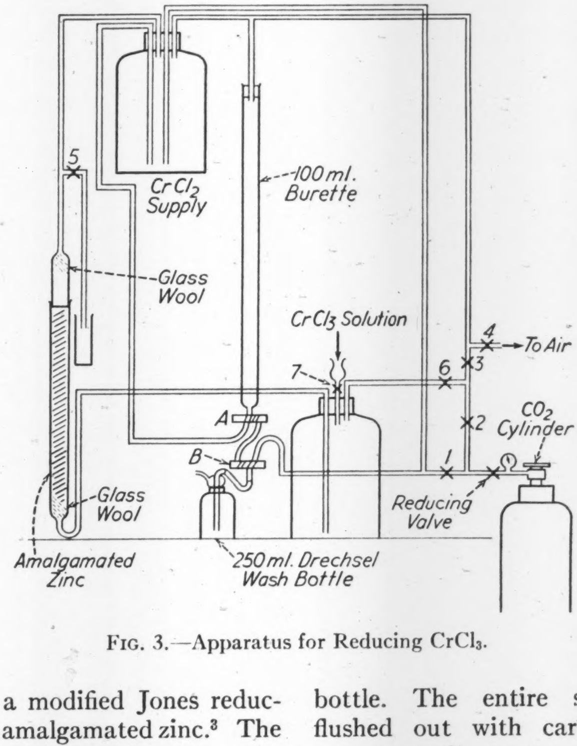

FIG. 3.—Apparatus for Reducing $CrCl_3$.

A solution consisting of 1000 ml. of 50 per cent chromic chloride solution, 500 ml. of concentrated hydrochloric acid and 500 ml. of distilled water is placed in the chromic chloride solution bottle. The entire system is then flushed out with carbon dioxide by a proper adjustment of the stopcocks. Stopcocks 1, 3, and 7 are now closed and 2, 4, 6, and 5 are opened. The reducing valve is opened so as to give a very small flow of carbon dioxide. This gas will force the acid chromic chloride solution up and over the amalgamated zinc and through stopcock 5 into a temporary receiver. Chromic chloride solutions are green and properly reduced solutions of chromous chloride are a brilliant blue color. When the solution leaving the reducing tube becomes blue, as it should after several minutes, stopcock 5 is closed and the reduced solution is collected in the reservoir, the displaced gas escaping through open stopcock 4. The rate at which the solution is passed over the zinc should be such that the hydrogen evolved will be approximately equal in volume to the solution being reduced.

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[3] H. W. Stone and C. Beeson, "Preparation and Storage of Standard Chromous Sulfate Solutions," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 8, p. 188 (1936).

After all the solution has been reduced stopcock 7 is opened and the reducing valve closed. Stopcock 2 is then closed and 1 is opened. When the two-way stopcock *B* is so turned that no gas can escape through it any leakage of carbon dioxide through the reducing valve will pass up through the glass tubing, bubble through the chromous chloride supply and escape through stopcock 4. This will prevent any backward diffusion of air into the system. Stopcock 4 is always open and has been placed there only to give the system flexibility. It is sometimes necessary to flush the system backwards in which case the air can escape through stopcock 7.

When it is desired to fill the Drechsel bottles with chromous chloride solution the following procedure is employed: A bottle is attached as shown in Fig. 3, stopcock 1 is opened, 2 is closed and the two-way stopcock *B* is set so that carbon dioxide will pass through the Drechsel bottle. The reducing valve is then opened enough to give a vigorous flow of carbon dioxide and the bottle is purged for about 5 min. While this is being done the two-way stopcock *A* is so turned that the solution will siphon from the reservoir and fill the burette. When the burette is filled, the stopcock is turned so that a connection is made between the burette and stopcock *B*. At the conclusion of the purging period, stopcock *B* is turned so that the solution will flow from the burette into the Drechsel bottle. The turning of this stopcock will of course cause the carbon dioxide coming from the cylinder to go up and bubble through the reservoir. It is necessary that it do this since we are removing material from the system which if not replaced would result in air being drawn in through stopcock 4. When 100 ml. of solution have been collected in the bottle, stopcock *A* is turned to a neutral position and *B* is turned so that carbon dioxide can again bubble through the bottle. This will sweep out the solution remaining in the line between *B* and the bottle. The bottle is then tightly stoppered by means of short pieces of gum rubber tubing and pinch clamps. No care need be taken to measure 100 ml. exactly, in fact a calibrated burette is unnecessary.

Three chromous chloride bottles are always used in series in the analyzer. Care must be taken that there is always one and preferably two blue bottles in the scrubbing train at all times. When a chromous chloride bottle is spent, as shown by the green color, another good bottle must be substituted for it. To effect a substitution a pinch clamp is placed on the short section of rubber tubing connecting the bottle to be removed and the one following it. The green bottle is then removed and a blue one put in its place. Gas is allowed to bubble through this bottle and into the air for 10 min. before connecting it into the train. Then the exit tube is inserted into the rubber tubing on the next bottle and the pinch clamp is immediately removed. This procedure must be followed in changing any bottle in the scrubbing train ahead of the catalyst.

All green chromic solutions are saved as they can readily be reduced again in the reductor. For every 1000 ml. of spent solution, 250 ml. of concentrated hydrochloric acid and 250 ml. of 50 per cent chromic chloride solution (new) are added and the mixture reduced as already described. The only function of the new chromic chloride solution is to prevent dilution. No limit to the possible number of regenerations has been discovered, accidental losses of liquor having provided adequate purging.

The possibility of reduction of the organic sulfur compounds in the gas by the chromous chloride was investigated by passing gas containing half a grain of organic sulfur per 100 cu. ft., but no hydrogen sulfide, through three chromous chloride bottles and testing the effluent gas for hydrogen sulfide, both with lead acetate test paper and by means of cadmium chloride. No hydrogen sulfide was found even when 100 cu. ft. of the effluent gas had been scrubbed with cadmium chloride solution.

Removal of Hydrogen Sulfide:

Whether or not the gas to be analyzed is known to contain traces of hydrogen sulfide, it is scrubbed with a slightly alkaline solution of cadmium chloride. This solution is the same as that used to absorb hydrogen sulfide after the catalyst and consists of 100 ml. of 10 per cent cadmium chloride solution to which 2 ml. of 10 per cent potassium hydroxide solution has been added. The Drechsel bottle containing this solution is placed after the chromous chloride bottles so that any hydrogen sulfide which may be liberated from impurities in the chromous chloride can also be removed from the gas. A bottle containing distilled water should always be placed between the chromous chloride bottles and the cadmium chloride bottle to catch any spray from the chromous chloride which would make the cadmium chloride solution acidic. Furthermore, the cadmium chloride bottle must also be followed by a water bottle so that any spray of cadmium chloride solution can be caught and thus prevented from entering the catalyst. If cadmium chloride is allowed to enter the catalyst tube, low results will be obtained because of formation of cadmium sulfide in the catalyst tube, an effect particularly noticeable in the relatively cool exit line.

Experimental evidence indicates that the absorption of small amounts of hydrogen sulfide by slightly alkaline cadmium chloride solution is practically quantitative. The capacity of a cadmium chloride solution for the complete absorption of hydrogen sulfide is relatively low, however, and after a considerable coloration of cadmium sulfide has developed in a bottle hydrogen sulfide will commence to leak through. The amount that may be absorbed in one bottle without leakage is roughly 0.2 grains of hydrogen sulfide. If the gas to be analyzed contains more than about 0.1 grains of hydrogen sulfide per 100 cu. ft. two cadmium chloride bottles should be placed before the catalyst. When the first bottle becomes a deep shade of yellow it should be replaced by a bottle containing fresh solution. The presence in the gas of varying percentages of carbon dioxide, up to 25 per cent, is believed to have no appreciable effect on the absorption of hydrogen sulfide by these solutions.

Catalyst Considerations:

The catalyst used is 8 to 10 mesh grade A activated alumina obtained from the Aluminum Ore Co., East St. Louis, Ill. It has already been pointed out that this catalyst adsorbs organic sulfur compounds. The amount of these compounds adsorbed varies with the temperature. The relationship is apparently an inverse one, that is, the higher the temperature the less the adsorption. Thus, if a run is started at 500 C. and ended at 550 C. the result will be high because some sulfur will be released from the catalyst. The temperature at which the catalyst should be held is about 500 C., with a variation of less than ±10 C. The most important items affecting temperature are the rate of gas flow and the line voltage, with drafts and changes in room temperature also having an appreciable effect. The temperature of the catalyst can be maintained constant either manually or by an automatic temperature control.

It is important to load the catalyst tube to such a depth that all of the catalyst may be at approximately the same temperature. This precaution minimizes any error resulting from slight changes in temperature during a run.

Since new catalyst, as obtained from the Aluminum Ore Co., contains some sulfur compounds that are given off when the catalyst is first used, a pretreatment of the catalyst preparatory to use is necessary. This treatment is most conveniently accomplished by passing cylinder hydrogen through the analyzer, with the catalyst at 500 C., at a rate of 3 to 5 cu. ft. per hr. for 24 to 48 hr. A longer period may be necessary if the gas to be analyzed contains less than 0.01 grain per 100 cu. ft.

Furthermore, when an analyzer is changed from a gas of one sulfur content to a gas of a materially different sulfur content, the analyzer should be purged for 24 hr. at the temperature and gas flow at which it is to be operated before a determination is started, so that the catalyst may attain an equilibrium with the gas at the operating temperature. During this purge period the apparatus, solutions, and conditions should be the same as those to be used during an analysis except that the final hydrogen sulfide absorption bottles need not be connected.

It is not known how long the catalyst will retain its activity; however, the catalyst has been used continuously for three months without showing any signs of lessening activity.

Laboratory Prepared Catalyst:

There has been developed recently for use in this method of analysis a specially precipitated alumina catalyst, which appears to be superior to the purchased activated alumina. When this catalyst is used with gases of low organic sulfur content (less than 0.01 grains per 100 cu. ft.) the correct result is obtained from the first run. Tests also indicate that it has no time lag with changing organic sulfur content of the gas in either direction.

The catalyst is prepared in glass or porcelain equipment from chemically pure aluminum nitrate by precipitating with ammonium hydroxide, care being taken to avoid any contamination. The following procedure illustrates the method of preparation:

One kilogram of aluminum nitrate (nine moles of water of crystallization) is dissolved in twelve liters of distilled water. The stoichiometric requirement of ammonium hydroxide is then slowly added with stirring. When precipitation is complete a viscous gel is obtained. The gelatinous precipitate is then filtered on a vacuum filter. The resultant filter cake contains considerable water and consequently an appreciable quantity of ammonium nitrate which if not removed is likely to decompose violently during the subsequent heat-treating operation. The major portion of this residual ammonium nitrate is removed by converting the cake to a slurry with three or four times its volume of distilled water, and refiltering. This filter cake is then dried overnight at 105 to 110 C. A considerable shrinkage takes place in this step. The dried material is then heat treated at 400 to 450 C. for several hours. The resulting alumina is then screened to the desired size and is ready for use. The fines are saved and mixed with the filter cake from the next preparation.

Sample Lines:

All gas-sampling lines should be of stainless steel or glass, and all rubber connections should be avoided so far as possible. Whenever a connection is made with rubber tubing, that connection should be as nearly a butt joint as possible so that a minimum surface of rubber will be exposed to the gas. Only sulfur-free pure gum rubber tubing should be used. Failure to observe these precautions is one of the most common sources of error in the use of the method.

Measurement of Gas Volume:

The gas volume passed through the analyzer during a determination is measured by a calibrated wet test meter connected to the second of the two hydrogen sulfide absorption bottles following the catalyst. The temperature of this meter, the pressure of the gas in it, and the barometric pressure should be read and recorded at intervals during the determination so that an average value may be obtained to be used in correcting the volume of gas to a dry basis at standard conditions.

Effect of Iron Carbonyl:

If the gas contains iron carbonyl, low results will be obtained because the carbonyl will decompose on the hot catalyst, depositing metallic iron which in turn will react with the sulfur causing a holdup. No method has been worked out for the analysis of gases containing iron carbonyl.

ANALYTICAL PROCEDURE

Collecting the Sample:

After the analyzer has been purged for the specified period at the operating temperature a run may be started. Two cadmium chloride bottles followed by the wet test meter set at zero are connected to the exit line of the catalyst tube. The desirable rate of gas flow will vary depending on the amount of sulfur in the gas. For low sulfur levels (0.002 to 0.10 grains of organic sulfur per 100 cu. ft.) a rate of 5 to 6 cu. ft. per hr. is used while for higher sulfur levels a rate of 3 cu. ft. per hr. will give enough cadmium sulfide for an accurate titration in a reasonably short time. When the first cadmium chloride bottle becomes distinctly yellow, enough gas has been passed and the run may be stopped by disconnecting the cadmium chloride bottles from the catalyst tube. The meter is then read and the two cadmium chloride bottles are titrated at once. If for any reason the bottles cannot be titrated immediately they should be tightly stoppered to prevent admission of air which will slowly oxidize the sulfide ion. Although no yellow coloration may appear in the second cadmium chloride bottle it should be titrated as a precaution.

Titration of the Sample:

When the amount of sulfide present is small, 0.01 *N* iodine and thiosulfate solutions are used, but for larger amounts 0.05 *N* or 0.1 *N* may be used. The concentration of the iodine solution should be such that at least 10 ml. of the iodine solution are used up in a titration by the sulfide ion. Occasionally, as when analyzing a gas containing 0.002 to 0.005 grains of organic sulfur per 100 cu. ft., it is not practical to wait for this much sulfide precipitate, since the analysis would have to extend over three or four days. The lower limit of normality with which accurate titrations can be obtained is about 0.005 *N*. Even at this normality it is rather difficult to detect the end point.

In this titration there is an end point correction which must be applied. This correction is determined in a solution of the same composition as that used in the titrations and is obtained by adding iodine solution until a blue color appears, 5 ml. of starch indicator having been added to the solution. This volume of iodine must be subtracted from the volume actually used in the titration. When the amount of sulfur being determined is small, this correction is of great importance. In case the gas contains any component besides hydrogen sulfide that will react with iodine, the blank should be run on a third bottle of cadmium chloride solution connected in the hydrogen sulfide absorption train during the run or the precipitate should be titrated only after the solution has been filtered off.

The starch indicator solution is made up by adding 5 g. of soluble starch indicator to 1 liter of water and acidifying by adding 10 ml. of 1 *N* hydrochloric acid.

The following procedure is used in making a titration. The glass stopper is raised and 5 ml. of 5 per cent potassium iodide solution is added to the absorption bottle. A measured volume of standard iodine solution is next run in, after which the inlet tube is washed both inside and outside with 20 ml. of concentrated hydrochloric acid and a small volume of distilled water. The volume of the solution should not be allowed to become larger than necessary. All cadmium sulfide should now be removed from the stopper which can be laid aside. Standard thiosulfate solution is now added until the solution is a pale straw color. Five milliliters of starch indicator are then added and the addition of thiosulfate continued until the blue color just disappears. Standard iodine is then added until the appearance of the blue end point color. When working with standard solutions of 0.005 to 0.01 *N*, the appearance of the blue color is harder to detect than the disappearance so that thiosulfate may be added to the end point in which case a different end point correction must be applied.

Calculation of Result:

The following equation is used to calculate the result:

$$\text{Grains of organic sulfur per 100 cu. ft.} = \frac{\text{ml. of iodine} \times \text{normality of iodine} \times 24.7}{\text{cu. ft. of gas passed}}$$

the volume of gas having been corrected to standard conditions (0 C., 760 mm., dry).

RESULTS OBTAINABLE

Amount Present versus Amount Found:

The accuracy of the method has been checked by analyzing gases of known sulfur content. Hydrogen was saturated with carbon disulfide at a given temperature and this gas was then diluted with more hydrogen in successive steps until the desired sulfur content was obtained. The following are typical results:

Sulfur Present, grains per 100 cu. ft.	Sulfur Found, grains per 100 cu. ft.
0.0042	0.0046
0.0057	0.0063
0.0045	0.0042
0.140	0.139
0.140	0.147
0.140	0.131
6.28	6.11
6.28	6.28

DISCUSSION

Mr. C. W. Rippie.[1]—May I ask the speaker if mercaptan sulfur is considered one of the constituents of the gas?

Mr. Lawrence T. Jilk.[2]—I would say that since the gases we deal with are derived mainly from coke, they contain principally carbon oxysulfide and carbon disulfide, and although I believe that the two mercaptans, methyl and ethyl, will be converted to sulfide, I have no definite proof. We know that thiophene is not completely converted.

Mr. Rippie.—I notice the statement is made that "Whether or not the gas to be analyzed is known to contain traces of hydrogen sulfide, it is scrubbed with a slightly alkaline solution of cadmium chloride," to remove the hydrogen sulfide. An article appearing in *Industrial and Engineering Chemistry*[3] indicates that a cadmium chloride solution will absorb mercaptan sulfur unless the solution is slightly acid. The absorbing solution will absorb only hydrogen sulfide and not mercaptan sulfur. If the method is applied to natural gas, it would be advisable to observe the alkaline condition of the absorbent solution. In petroleum work on gasoline it is necessary to have that absorbent solution slightly acidified to avoid the absorption of mercaptan sulfur.

Mr. Jilk.—I have noticed that reference to hydrogen sulfide. We never worry about it because we do not have much mercaptan sulfur in our case. I would suggest that the hydrogen sulfide be allowed to remain in the gas and then determine hydrogen sulfide by another method, such as lead sulfide precipitation.

Mr. Rippie.—Mr. Jilk's method provides a very good technique, if the solution is slightly acidified, to absorb hydrogen sulfide only.

Mr. Jilk.—Hydrogen sulfide would be entirely removed?

Mr. Rippie.—Yes, completely.

Mr. H. C. Porter.[4]—I should like to inquire as to the application of this method to coal gas, from distillation of coal; the organic sulfur there is present as mercaptan, carbon disulfide and a number of other sulfur compounds. Has the author had experience in applying the method to that complex mixture?

Mr. Jilk.—We have used the method on coke oven gas and obtained results which check the sulfur burner method [see author's closure.—Ed.]

Mr. Porter.—City gas is quite largely made either by distillation of coal or by the carburation of water gas. It is important to have some method for determining organic sulfur. The burner method is quite commonly used, getting total sulfur and then subtracting the hydrogen sulfide. I thought possibly Mr. Jilk had experimented with those gases.

Mr. Jilk.—We have used the method on coke oven gases. The organic sulfur in coke oven gas, we believe, consists of 90 per cent carbon disulfide and the results are sufficiently accurate when that much carbon disulfide is present. As regards other impurities, I believe that mercaptans are converted, but we know that thiophene is not completely converted.

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[1] Petroleum Technologist, Solvay Sales Corp., New York City.

[2] Chemical Engineer, Ammonia Dept., E. I. du Pont de Nemours and Co., Inc., Charleston, W. Va.

[3] Faragher, Morrell, and Monroe, "Quantitative Determination of Sulfur and Sulfur Derivatives of Hydrocarbons in Naphtha Solutions," *Industrial and Engineering Chemistry*, Vol. 19, November, 1927, p. 1281.

[4] Chemical Engineer and Chemist, Philadelphia, Pa.

MR. E. L. BALDESCHWIELER.[5]—I should like to ask the author whether he has done any work on sulfides and disulfides. These organic sulfur compounds are quite frequently present in petroleum gases.

MR. JILK.—Of course we never have used the method for the determination of organic sulfur in petroleum gases. It may have some application there, but we do not know.

MR. A. C. FIELDNER.[6]—Committee D-3 on Gaseous Fuels is very much indebted to the authors for presenting this paper. It should be understood that this is not being offered as a standard method by the committee, but is presented as a part of the committee's program of seeking better methods for determining small percentages of organic sulfur in gas.

MR. H. P. FERGUSON.[7]—Since we gather that this work may have some bearing on the methods of analysis developed as a result of the work of Committee D-3, our remarks are in the nature of a warning. It is entirely possible that the author's method is not applicable to natural gas. The petroleum industry is using activated alumina as a reforming catalyst, and I am afraid that since the temperatures are normally of the same order of magnitude, a side reaction with natural gas may occur which would change the volume relationship entirely so far as the measurement of organic sulfur is concerned.

MR. JILK (*author's closure by letter*).—In reply to Mr. Porter's question concerning the use of the method on coal gas, I stated that the method had been used on coke-oven gas with results checking the sulfur burner method. I now find this to be a misstatement in that check analyses of coal gas by the burner method have never been made.

Mr. Ferguson pointed out the possibility of a change in volume relationship if the method were used on natural gas. I should like to suggest in this connection that if a change in volume should occur, the gas could be metered before passage through the analyzer.

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[5] Chemist, Standard Oil Development Co., Elizabeth, N. J.

[6] Chief, Technologic Branch, U. S. Bureau of Mines, Washington, D. C.

[7] Chemical Engineer, Standard Oil Co. (Ohio), Cleveland, Ohio.

RECENT EXPERIMENTS ON LABORATORY WET GAS METERS

By Howard S. Bean[1] and F. Charles Morey[1]

Synopsis

In the determination of the heating value of industrial fuel gases it is customary to measure the quantity of the gas burned in a calorimeter during the test period by means of a small meter of the water sealed drum type. In considering improvements in calorimetric practice attention must be given to the measurement of the gas volumes.

Possible sources of uncertainty in the meter indications include: use of fractional revolutions of the meter drum; failure to have the sealing water saturated by the gas; variation in the relative humidity of the gas entering; effects of oil fog carried by the gas; differences in temperature of the room, the sealing water and the gas; the method of calibrating the meter.

This paper presents a review of the tests made by members of the Subcommittee on Measuring Gaseous Samples of the A.S.T.M. Committee D-3 on Gaseous Fuels, to determine the possible effects of these various sources of error.

During the past 10 yr. there has been much attention paid to the determination of the heating value of industrial fuel gases. One of the most important reasons for this is the practice of making the price paid for the fuel gas depend in some degree upon the average heating value of the gas during the account period. In the determination of the heating value, by the use of a calorimeter, either the weight or the volume of the gas burned must be known. In general this quantity of gas is determined by volumetric measurement, although this method makes it necessary to make subsidiary measurements of pressure, temperature, and humidity. The most common method of measuring the gas volumes is to use a small meter of the wet, or water-sealed, drum type. It is evident that any inaccuracy in the measurement of the gas volume will be directly reflected in the reported heating value of the gas per unit volume. Therefore, if any improvement is to be made in the accuracy of gas calorimetry, one of the factors to be considered will be that of the volume measurements.

The meters are commonly made of heavily tinned sheet metal. For use with calorimeters in this country, the size of the drum and case are so proportioned that 0.1 cu. ft. of gas is measured with each complete revolution of the drum, provided the height of the sealing water has been correctly adjusted. The details of construction and mode of operation of these meters are probably sufficiently familiar to most readers that it will be unnecessary to describe them here.

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[1] Senior Physicist, and Assistant Physicist, respectively, National Bureau of Standards, Washington, D. C.

The calibration of these meters consists in determining the correct height of the surface of the sealing water. This is most commonly done by comparison with the volume of gas discharged from a 0.1-cu. ft. bottle. Another method would be to calculate the volume of gas drawn through a meter during one or more full revolutions from the corresponding weight of water displaced in an aspirator bottle.[2] A third method of calibration is with a gas meter prover. The degree of accuracy attainable by this method will be relatively low unless the prover has been specially prepared for this work. The details of these methods of calibration and their relative advantages and possible sources of error will be discussed later.

TABLE I.—VOLUMES OF GAS DELIVERED IN FRACTIONAL REVOLUTIONS OF METER.

Fractional Revolution	Volume of Gas Delivered, cu. cm.[a]	Volume Delivered Divided by 2820
0.250	732	0.260
0.333	972	0.345
0.500	1474	0.523
0.667	1924	0.682
0.750	2156	0.765
1.000	2820	1.000

[a] The method of calibration used in the experiments summarized in this table was the aspirator bottle method.

Uncertainties and errors in gas volumes determined from the indication of these meters may arise from one or more of the following sources:

The use of fractional revolutions of the meter drum;

Failure to have the sealing water in the meter saturated by the gas, and variation in the relative humidity of the gas entering the meter;

Effects of an oil fog carried by the gas;

Difference between the temperatures of the room, the meter sealing water, and the gas entering the meter; and

The method of calibrating the meter.

The Subcommittee on Measuring Gaseous Samples, of the Society's Committee D-3 on Gaseous Fuels, has been studying these various sources of error through tests which different members of the committee have made. This paper reviews these tests, so far as they have gone. Mention is also made of additional tests in progress, or planned, and it is hoped that the discussion of this paper will suggest other conditions which should be given consideration by the committee.

POSSIBLE ERRORS IN THE USE OF FRACTIONAL REVOLUTIONS

In their paper on Industrial Gas Calorimetry[2] Waidner and Mueller state:

> "The use of fractional turns may lead to significant errors, . . ."
>
> "For example, a test of one of these meters, the motion of the index of which over the scale was very regular, gave the results shown in Table 6 [the accompanying Table I].
>
> "It will be seen that the volume of gas delivered in the second half revolution was 8.7 per cent less than in the first half revolution, and the volume delivered in the last one-third revolution was 7.8 per cent less than in the first one-third revolution. The quarter revolutions show similar differences. These meters should, therefore, be calibrated and used for total revolutions or, if fractional revolutions must be used, the particular portion of the scale used must be calibrated."

More recently M. F. Kleeberg[3] made a series of tests to determine the limitations of the 0.1-cu. ft. wet test meter for making measurements of less than 0.1 cu. ft., or of non-integral multiples of a revolution. Mr. Kleeberg's report to the committee is given below in considerable detail:

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[2] C. W. Waidner and E. F. Mueller, "Industrial Gas Calorimetry," *Technologic Paper No. 36*, Nat. Bureau Standards, p. 35 (1914).

[3] Senior Calorimetry Inspector, Peoples Gas Light and Coke Co., Chicago, Ill.

Method:

"The facilities of the laboratory of the Peoples Gas Light and Coke Co. did not include suitable calibrated standards for making direct comparisons of gas volumes of less than 0.1 cu. ft. so the following indirect method was employed.

"Three meters were chosen at random from our reserve store:

American Meter No. 1248
American Meter No. 5064
Sargent Meter No. 2363

"The American Meter No. 1248 was carefully standardized and was then connected in series with the other two meters in a constant temperature room.

TABLE II.—SUMMARY OF DATA SHOWING THE MAGNITUDE OF ERROR WHICH CAN BE EXPECTED WHEN USING FRACTIONAL PARTS OF A 0.1 CU. FT. WET TEST METER.[a]

American Meter No. 1248 (0.1 cu. ft. per revolution)						American Meter No. 5064 (0.1 cu. ft. per revolution)		Sargent Meter No. 2363 (0.1 cu. ft. per revolution)	
A	B	C	D	E	F	G	H	I	J
0	0	0	0	0	0	0	0	0	0
0.01	0.01	14.9	+0.5	+0.000347	−0.35	0.0107	0.0107	0.0101	0.0101
0.02	0.01	14.2	−0.2	−0.000139	+0.14	0.0201	0.0094	0.0204	0.0103
0.03	0.01	13.4	−1.0	−0.000694	+0.69	0.0293	0.0092	0.0298	0.0094
0.04	0.01	13.8	−0.6	−0.000417	+0.42	0.0400	0.0107	0.0406	0.0108
0.05	0.01	13.1	−1.3	−0.000903	+0.90	0.0490	0.0090	0.0498	0.0092
0.06	0.01	14.4	±0	±0.000000	±0.00	0.0596	0.0106	0.0600	0.0102
0.07	0.01	15.1	+0.7	+0.000486	−0.49	0.0699	0.0103	0.0706	0.0106
0.08	0.01	14.6	+0.2	+0.000139	−0.14	0.0794	0.0095	0.0796	0.0090
0.09	0.01	16.2	+1.8	+0.001250	−1.25	0.0894	0.0100	0.0903	0.0107
0.10	0.01	14.3	−0.1	−0.000069	+0.07	0.1000	0.0106	0.1000	0.0097

[a] Columns A, G, I = Meter reading, cu. ft.
B = Volume of gas indicated by large hand per 0.1 revolution, cubic feet.
C = Time for meter hand to pass between each 0.01-cu. ft. mark on dial, seconds.
D = Difference between actual and average (14.4 sec.) time for each 0.1 revolution of meter drum.
E = Excess or deficiency from average amount of gas entering meter drum per 0.1 revolution. This figure is derived by calculation, on the assumption that if all compartments of the meter drum were constructed of equal capacity and shape, the drum was perfectly balanced, and friction was equal at all points of rotation, then the flow of gas from a constant source would be constant through the meter and the meter would register an equal volume of gas during each second of its rotation.
F = Percent of error per revolution of large meter hand. If measuring 0.01 cu. ft. multiply by 10.
H, J = Indicated volumes passed by meters per 0.1 revolution of meter No. 1248, cu. ft.

"City gas was allowed to pass through the meter train at the rate of 2.5 cu. ft. per hour, and meters Nos. 5064 and 2363 were adjusted to register the same amount of gas as meter No. 1248.

"Readings of the three meters were then taken by stopping meter No. 1248 at each 0.1 revolution of the meter hand. These results are shown in the summary table [the accompanying Table II] under columns *A*, *G*, and *I*.

"Operating the meter train at the same rate, the time for the meter hand of meter No. 1248 to pass through each 0.1 division of the dial was noted."

Theory and Calculation:

"The total time for the meter hand to make one complete revolution was 144 sec. which indicates 14.4 sec. as the average time to pass through 0.1 division of the dial.

"The difference between 14.4 and the actual times noted in column *C* of the summary table represented the time (column *D*) the meter drum lagged or accelerated due to inaccuracies in the construction of the meter. As there was a supply of constant pressure gas to the outlet, it must be true that different amounts of gas were entering the drum compartments due to volume or pressure changes at different positions during the rotation cycle. As this amount of gas is directly proportional to the time, it can be calculated (column *E*).

"The per cent of error in measurement is calculated from this excess or deficiency between each 0.1 division of the dial (column *F*).

"For meter No. 1248, a maximum error of minus 1.25 per cent of one complete revolution was noted between the 0.8 and 0.9 divisions of the dial. If the quantities to be measured are of the magnitude of 0.01 cu. ft. this error should be multiplied by 10.

"The results of the readings on meters Nos. 5064 and 2363 give additional proof that fractional divisions of a 0.1 cu. ft. meter are unreliable, although no attempt was made to calculate the errors on these meters due to the fact that the delivery rate from meter No. 1248 was not constant."

From his own tests and that of Waidner and Mueller given above, Mr. Kleeberg concludes "that fractional revolutions of a 0.1-cu. ft. meter cannot be relied upon for accuracies greater than 90 per cent when using these meters to measure gas samples as small as 0.01 cu. ft. unless the divisions are especially calibrated."

It is desirable to call attention to a detail which both of the conclusions quoted above fail to bring out. Both state that if fractional revolutions are to be used the "portions" or divisions of the scale should be calibrated. Now the errors due to the use of fractional revolutions arise not from any unevenness in the graduations of the meter scale or index, but from the practical difficulty (or impossibility) of making the capacities of the several compartments of the drum equal. Since the large hand of the meter serves only to indicate the relative position or degree of rotation of the drum with respect to the index, it follows that if, after making a calibration of the scale, the large hand is shifted with respect to the drum, the calibration is rendered worthless. To overcome this point of weakness it has been suggested that the large hand be fitted to the drum shaft with a key, or by the use of an irregular shape of hub and shaft so that in case of removal it may be returned to the same position with respect to the drum as before.

Other errors which may result from the shifting of the large hand on the drum shaft of a 0.1-cu. ft. wet meter are discussed in the following memorandum to the Subcommittee from Mr. Kleeberg:

"Experience and a study of the construction and characteristics of these meters has shown that if the meter is operated by using complete revolutions, there are only two possible sources of error to be caused by a shifting meter hand:

1. Error caused by meter hand slipping during operation.
2. Error caused by checking level of water at improper position of the meter drum.

"The first source of error can be remedied mechanically by assuring a tight, nonslip connection between the hand and the drum shaft.

"The second source of error requires the careful attention of the operator. The construction of a 0.1-cu. ft. meter is such that the large hand is held in position relative to the drum shaft by a knurled nut which has a tendency to become loosened during handling. When this nut is retightened, the meter hand usually assumes a different position relative to the drum. If the hand is reset to coincide with one of the four cupping and uncupping points on the drum, an error will be introduced when the water level of the meter is checked due to the fact that at and adjacent to (within three or four small divisions of the dial) any one of the four cupping points the water level will assume a different level (different by $\frac{1}{64}$ in. to $\frac{1}{8}$ in., depending upon the meter) than normally exists at the other positions of the drum.

"Several meters were investigated and it was found that the error caused by adjusting the water level at the uncupping points instead of one-half way between them varied with the different meters tested from 0.2 per cent to 1.0 per cent.

"It is suggested that immediately after a meter has been compared with a standard prover and adjusted, that the large hand be set at some convenient point—100, 75, 50, or 25—and the drum shaft rotated so that the two cupping points nearest the hand be placed one-eighth of a revolution away. The four cupping points on a drum are equidistant from each other, and they can be determined by passing gas through the meter and watching the water level gage for the characteristic sharp rise and fall of the meniscus. After the hand has been set, it is advisable either to solder it to the drum shaft or to make some distinguishing mark on the shaft so that the proper setting may be reproduced in case the hand becomes loosened.

"The best procedure is always to check the water level at the same position of the drum."

Effect of the Relative Humidity of Gas Entering the Meter upon the Indications of the Meter and the Relative Humidity of Gas Leaving the Meter

In *Industrial Gas Calorimetry* it is stated that the calibration of a meter supplied with dry gas did not change more than 0.1 per cent from the calibration obtained with saturated gas. It is stated also that humidity tests of the gas delivered by the meter when supplied with dry gas showed the gas delivered to be saturated at the meter temperature.

These statements have undoubtedly contributed to the fairly common practice of more or less neglecting the relative humidity of the gas entering a meter and assuming the gas leaving the meter to be saturated with water vapor. Recently, new tests along this line were made for the Subcommittee by Messrs. J. H. Eiseman and F. A. Smith at the National Bureau of Standards, the results of which may be summarized as follows:[4] When dried air was delivered to a laboratory wet test meter, the degree of water vapor saturation of the air leaving the meter varied from 97 to over 99 per cent. They therefore concluded that the completeness with which such a meter saturates even dry air is at least 98 per cent at any practicable rate of flow. Since the volume of the water vapor involved will usually amount to less than 3 per cent of the total indicated volume, the error resulting from (a possible 2 per cent) incompleteness of saturation will be less than 0.06 per cent of the volume indicated by the meter.

To obtain a basis for estimating the possible error in the indications of a meter that may result when the gas entering a meter is dry, air was passed through two meters in series. In one test the air entering the first (or test) meter had been saturated with water vapor while in the next test the air had been dried. Such pairs of tests were made at both high and low rates of flow. The meter indications were referred to a common pressure and temperature for comparison. This comparison indicated that when dry air entered the test meter the indications were too low by about 0.15 per cent.

Some additional tests were made to see what effect tilting of the meter would have upon its indications. It appeared that if the tilting, either sidewise or from front to back, occurred *after* the quantity of water had been correctly established with the meter level, there resulted no consistent or significant error so long as no water was added or removed from the meter. On the other hand if the gage mark indicated the correct amount of water with the meter *level*, the setting of the water surface to the gage mark when the meter was not accurately leveled introduced an appreciable error, possibly as much as 1 per cent. The magnitude of the error will of course depend on the amount of tilting, which will govern the amount of water added or removed to bring the water surface to the (incorrect when tilted) position of the gage mark.

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[4] A detailed account of these tests will be presented in an early issue of the *Journal of Research*, Nat. Bureau Standards.

EFFECTS OF OIL FOG ON METER INDICATIONS

Another possible source of error in test meter indications may arise from the presence of an oil fog carried by the gas. During the course of the routine work, some observations of the possible errors from this source have been made at the American Gas Association Testing Laboratory. R. M. Connor, Director of the Laboratory, has made the following report on these observations:

"It is common knowledge that saturation of natural gas with oil fog, produced by atomization of the oil through high-velocity injection means, produces a mist of small particles which fall out of the gas stream as it is carried through the lines. Such oils are usually selected for their tendency to settle out in liquid form to wet the surfaces of pipes, meter diaphragms and other distribution equipment. The distance any given particle may travel depends on the gas velocity, gas pressure, and the size and nature of the oil particle. Due to these variations the amount of oil particles (oil saturation) at any distance from the point of fogging is an unpredictable quantity. Therefore, a theoretically accurate measurement of such gas requires that all traces of oil fog be removed before passing through a wet test meter. Deposition of the oil in liquid form will probably alter the vapor pressure of the water and the gases dissolved in it and extreme saturation might result in the forming of an undesirable oil emulsion.

"Traces of the oil fog may be removed by allowing the gas to stand until the fog settles, by mechanical filtration, or by bubbling through cold water in fine streams. Any one or all three methods should be used as warranted by the conditions of measurement.

"However, consideration should also be given to the possible error introduced by the use of absorbers or filters for fog removal which may change the heating value of the gas by dissolving some of the gas constituents in the accumulated oil liquid.

"Complete evaporation of the fogging oil at the rate of 2.5 gal. per 100,000 cu. ft. of natural gas would add less than 0.4 per cent to the heating value and less than 0.05 per cent to the volume of the gas, assuming 150,000 B.t.u. per gallon of oil. However, evaporation might be wholly neglected as a large portion will condense in drips and on pipe walls. Therefore, attention was focused on the effect of the precipitation of the liquid oil on the surface of the water in a wet test meter.

"Inasmuch as the manufactured and natural gases regularly used at the Testing Laboratories are not saturated to any degree by the process known as 'oil fogging,' it was necessary to duplicate by experiment the effect of oil deposited on the surface of the water in a wet test meter during the conduct of some of the routine test work on gas appliances.

"To determine the effect of liquid oil deposited in a test meter on its accuracy, two such meters were operated in series. The water in both meters was saturated with the gas before the tests. The accuracy of the second meter (a 10-light wet test meter) relative to the first meter (a 5-light wet test meter) was determined by running about 285 cu. ft. of natural gas through the two meters in 7 hr. Two such comparative runs were made. For the third run, 27 ml. of 33.5° Baumé gas oil was poured into the second meter immediately before the run was started. This amount of oil is approximately that required to 'fog' 285 cu. ft. of gas at the rate of 2.5 gal. per 100,000 cu. ft., and represents the maximum amount of oil that could be added to the meter by the passage of such an amount of 'fogged' gas. The results are shown below:

Run	No. 1 5-Light Meter, cu. ft.	Measured No. 2 10-Light Meter, cu. ft.	Deviation Meter No. 2		Remarks
			cu. ft.	per cent	
No. 1	284.75	285.62	+0.87	+0.33	
No. 2	281.01	281.75	+0.74	+0.26	
No. 3	285.75	286.00	+0.25	+0.09	27 ml. 33.5° Baumé gas oil added before start of run

NOTE.—Gas rate about 40 cu. ft. per hour.

"The results of the first two runs indicate a reproducibility of results within 0.07 per cent of the volumes measured under the conditions of the test. Those of the final run indicate that the deposition of all the oil from 285 cu. ft. of natural gas fogged at a rate of 2.5 gal. per 100,000 cu. ft. would slow the meter about 0.2 per cent."

RELATIONS BETWEEN TEMPERATURES OF ROOM, METER, AND GAS

One of the questions that is asked about laboratory meters is: "Within what limits must the temperatures of the room, meter, and gas entering the meter be the same." Another way of asking this question is: "If the temperatures of the meter, room, and incoming gas are all different, does the temperature of the gas as metered come nearer to being equal to that of the meter or room?" It has been difficult to obtain experimental data for the answer to this question because in addition to the usual difficulty of obtaining gas temperatures unaffected by external influences the construction of these meters is such as to make gas temperature measurements within it especially difficult. In order to obtain additional data on this, the Precision Scientific Co. of Chicago was asked to make a series of tests to show how the gas and meter temperatures follow the room temperature when they start from different values initially. In his report on these tests, Mr. Alexander Newman, Vice-President of the Precision Scientific Co., states that in preparing for them an attempt was made to duplicate the conditions often encountered in a laboratory on winter mornings. If the laboratory were not heated during the night, the wet test meter would be cold when work was started in the morning, while the gas coming through the pipes in the building would enter the meter at approximately room temperature.

"The equipment used in the tests included:

1. Sargent wet test meter 0.1 cu. ft. model, Serial No. 8798B.
2. 'Precision' low temperature cabinet equipped with heaters and a door with triple glass and insulation.
3. Fifteen feet of $\frac{1}{4}$ in. outside diameter copper tubing wound into a coil of 4 in. outside diameter and mounted in the cabinet.
4. Seven nickel wire resistance thermometers of No. 40 gage wire with 6 ft. copper leads. These were waterproofed before calibration.
5. Two seven-point tap switches.
6. Leeds & Northrup Wheatstone bridge testing set No. 5410.
7. Suspended coil, reflecting type galvanometer with light source and with scale placed at 2 m.
8. 'Precision' 12-in. water manometer.
9. Wet type pressure governor.
10. Auxiliary equipment such as dry cells, gas burner, etc.

"To prepare for the tests, the meter was placed in the low-temperature cabinet and connected to the gas supply with rubber tubing, so that the incoming gas first passed through the pressure governor and manometer tee connection, then through the door of the low temperature cabinet, through the copper coil in the cabinet, through the meter, and then out to the burner located outside of the cabinet.

"The resistance thermometers were connected to the Wheatstone bridge through the tap switches. The connections were made to use the Siemans 3-lead compensation, as described in National Bureau of Standards *Bulletin No. 170* (Pyrometric Practice), so that errors due to changing resistance of the lead wires would not effect the readings.

"Gas from the city mains was run through the assembly for several hours, to saturate thoroughly the water in the equipment. The cabinet was then run overnight at about 40 F., to cool thoroughly all parts of the meter and the contained water.

"The next day the gas was regulated to flow through the meter at the rate of 2.3

cu. ft. per hour. The heater in the cabinet was turned on and resistance readings of the resistance thermometers taken at approximately 1-min. intervals, and recorded with the time of the reading to the nearest second. The temperature of the cabinet rose to a maximum and then regulated near that temperature for the remainder of the test period of nearly 4 hr.

"The resistance readings were converted to temperature to the nearest 0.01 deg., and the temperature of each resistance thermometer plotted against the elapsed time in seconds, as shown on the chart [the accompanying Fig. 1][5]."

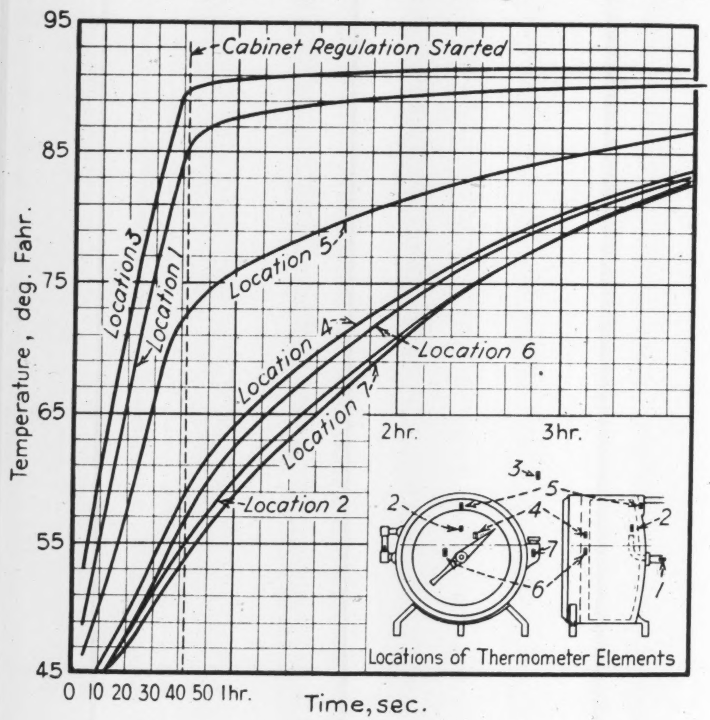

FIG. 1.

METHODS OF TESTING LABORATORY WET GAS METERS

The usual method of testing a laboratory wet gas meter is with a 0.1-cu. ft. bottle. This method does not correspond to the conditions under which the meters are used in several important respects. In the first place, in this method of test the meter starts from rest and stops at the end of the test, whereas in use, particularly in calorimetry work, the meter is in motion at the start and finish of the test.

In the second place, the rate of air flow through the meter during the test varies from a maximum at the start to a very gradual stop at the end. In calorimeter work special attention is given to maintaining the rate of flow constant. Also the average rate at which the test is made is very much slower than that at which it is generally operated.

To overcome some of these objections, it seemed desirable to see if other equipment and methods could be developed for testing these meters. After some discussion in the committee it was decided to first see if some of the equipment common to gas meter shops could be adapted to this purpose, before trying to design new apparatus which would not be generally available. Accordingly the American Meter Co. was asked to lend the National Bureau of Standards a 2-cu. ft. gas meter prover which it was hoped could be calibrated with sufficient accuracy to be used in testing these meters. Since it would not be possible to make direct readings reliably with both the meter and prover in motion, it was decided to have the large hand of the meter actuate one pen of a chronograph through a light contact breaker. The other chronograph pen was to be actuated from strikers clamped to the prover scale. The prover calibration would consist of determining the volumes represented by the distances between the contact surfaces of these strikers. It was hoped that the calibration of these intervals could be made to an accuracy of at least plus or minus 0.0001 cu. ft., which is the figure to which the reading of most laboratory meters can be estimated.

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[5] A number of constructive comments on these tests and the results have been made by members of the subcommittee and therefore it is planned to conduct further tests of this kind later.

After some six months of effort it has not been possible to obtain successive calibrations of the prover intervals which are consistent to better than plus or minus 0.0015 cu. ft. although the work was done in a constant-temperature room and corrections for the effects of such influences as sealing fluid run-down and small changes in barometric pressure were made. It is believed therefore, that it will be necessary to develop some other equipment to be used as a volume standard in testing these meters if any real improvement is to be made.

A MECHANICAL OSCILLOGRAPH FOR ROUTINE TESTS OF RUBBER AND RUBBER-LIKE MATERIALS

By Felix L. Yerzley[1]

Synopsis

Describes a mechanical oscillograph which has been developed for routine laboratory tests of rubber and rubber-like compositions intended for cushioning services. It may be used to measure:

1. Static characteristics: (*a*) loading and unloading, (*b*) creep under a given dead load, and (*c*) set.

2. Dynamic characteristics: (*a*) energy absorption during impact loading, (*b*) resilience, and (*c*) effective dynamic modulus.

Data are obtained in fundamental units which should be useful both to rubber technologists and to mechanical engineers.

Object:

The use of rubber and similar substances for vibration and shock isolation has created a need for tests of the mechanical properties involved in such service. At a given temperature, these properties are modulus under slow or practically static conditions, dynamic modulus, energy absorption by hysteresis loss, and creep under a given dead load. In a previous paper the author presented a qualitative description of a method that might be used for these measurements.[2] In the present paper the method is developed in detail to permit the attainment of significant numerical data in fundamental physical units.

Principles of Static Tests:

Figure 1 shows the present form of the machine. As shown diagrammatically in Fig. 2, the machine consists of a balanced lever supported at its center by knife edges and a set of standard weights which may be added at one end to compress a test specimen *A* on the opposite side of the knife edges. A second knife edge and a stabilizing arm are introduced to render the compressing surfaces essentially parallel. Perfect balance of the lever may be obtained by adjusting the position of the counter-balance *B*. A pen arm extending from the heavy end of the lever automatically records deflections on the chart or oscillogram.

By an examination of Fig. 2 it is obvious that the deflection of the rubber will be magnified in proportion to the lever ratio, which is 16.0 to 1.60. In other words a compression of 0.10 in. will be registered on the oscillogram as a vertical displacement of 1.00 in.

The weight *W* in Fig. 2 consists of several brass disks, each weighing 1.410 lb. The lever ratio for the weights is 10.0 to 1.60. Each weight on the end of the lever, therefore, results in a force of

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[1] Physicist, Rubber Chemicals Division, Organic Chemicals Dept., E. I. du Pont de Nemours and Co., Inc., Wilmington, Del.

[2] F. L. Yerzley, "The Evaluation of Rubber and Rubber-Like Materials as Vibration Absorbers, "*Industrial and Engineering Chemistry*, Analytical Edition, Vol. 9, p. 392 (1937).

$$1.41 \text{ lb.} \times \frac{10.0}{1.60} = 8.82 \text{ lb. on the test specimen}$$

The test specimens are vulcanized in a cylindrical mold cavity $\frac{1}{2}$ in. high and $\frac{3}{4}$ in. in diameter. Their nominal cross-sectional area is 0.441 sq. in. and the unit load resulting from each weight is, therefore,

$$\frac{8.82}{0.441} = 20 \text{ psi.}$$

It can be seen by reference to Fig. 1 that the upper platen or loading surface of the machine can be raised or lowered by turning the micrometer head. This feature is important because it enables compensation to be made for slight variations of test specimens from their nominal height and because test specimens not of standard size can be tested

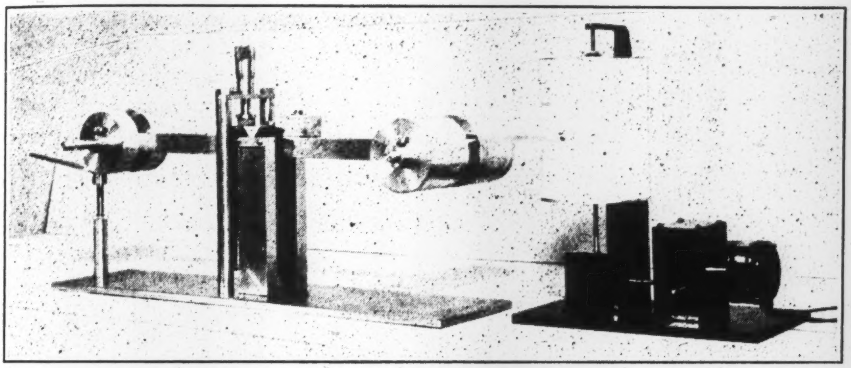

FIG. 1.—The Oscillograph.

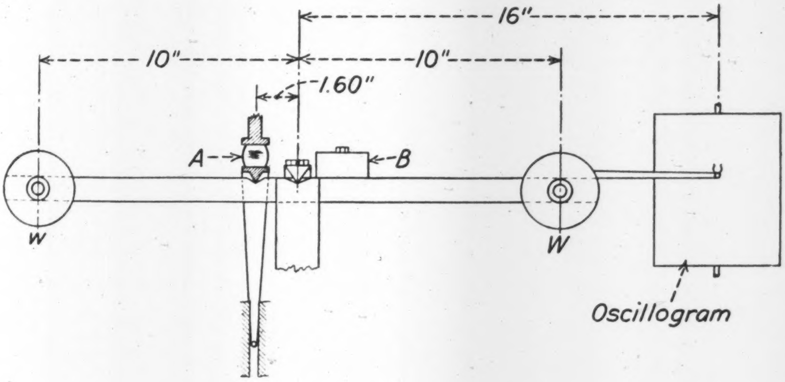

FIG. 2.—A Diagrammatic Description of the Oscillograph.

Analysis of Oscillations:

Figure 3 shows three positions of the apparatus necessary for an analysis of the oscillations consequent to sudden release of the unbalanced lever from an elevated position. The position of the lever corresponding to zero deformation of the test specimen is shown in

Fig. 3 (*a*). When the lever is released, the heavy end falls, compressing the rubber, and during the ensuing time interval the oscillations occur. The deflections of the rubber are plotted autographically against time making a graph like those of Fig. 4.

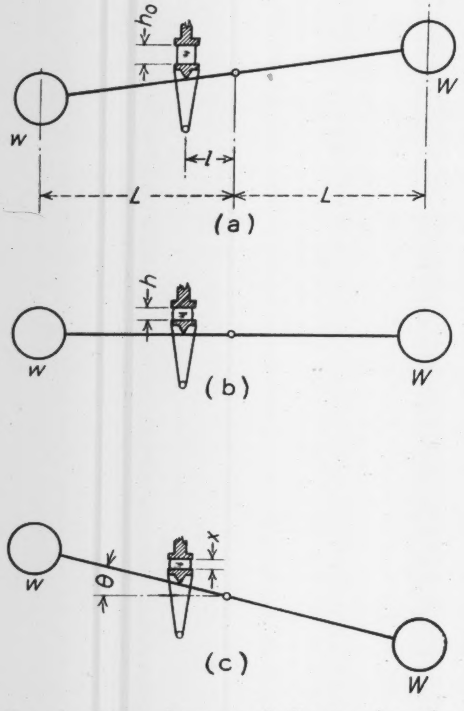

FIG. 3.—Three Degrees of Compression of a Test Specimen.
(*a*) Undeformed.
(*b*) Static equilibrium under load.
(*c*) Any instantaneous deformation during a dynamic test.

At the instant of release of the lever in the position of Fig. 3 (*a*) the lever is accelerated by a torque equal to $(W\text{-}w)L$. In Fig. 3(*b*) the lever is shown at rest with the torque due to gravity counterbalanced by the torque resulting from compression of the test specimen.

That is:

$$(W - w)L = K'\frac{(h_0 - h)}{(h_0)}l \ldots\ldots(1)$$

where W = weight on heavy end of lever,
w = weight on light end of lever,
h_0 = undeformed height of test specimen,
h = height of pellet under equilibrium load, and
K' = assumed spring constant.

At any instant during the vibrations the angular deflection from the equilibrium position can be represented by 0 in Fig. 3(*c*) where x represents the corresponding height of the test specimen. Therefore, at any instant, spring reaction on the loading platform $= K'\frac{(h_0 - x)}{(h_0)}$ and the corresponding torque $= K'\frac{(h_0 - x)}{(h_0)}l$. If I is the total moment of inertia of the lever and the weights about the main fulcrum and $\frac{d^2\theta}{dt^2}$ is the angular acceleration

$$I\frac{d^2\theta}{dt^2} = (W - w)l - K'\frac{(h_0 - x)}{(h_0)}l \ldots(2)$$

Substituting Eq. 1 in Eq. 2

$$= K'\frac{(h_0 - h)}{(h_0)}l - K'\frac{(h_0 - x)}{(h_0)}l \quad (3)$$

$$= K'l\frac{(x - h)}{(h_0)}$$

or

$$I\frac{d^2\theta}{dt^2} - K'l\frac{(x - h)}{(h_0)} = 0 \ldots\ldots(4)$$

If the static equilibrium position of the lever is approximately horizontal, for small angles

$$\theta = \frac{h - x}{l}$$

$$\frac{d\theta}{dt} = -\frac{1}{l}\frac{dx}{dt}$$

$$\frac{d^2\theta}{dt^2} = -\frac{1}{l}\frac{d^2x}{dt^2} \ldots\ldots\ldots\ldots(5)$$

Substituting Eq. 5 in Eq. 4

$$\frac{-I}{l}\frac{d^2x}{dt^2} - K'l\frac{(x-h)}{(h_0)} = 0 \ldots\ldots (6)$$

$$\frac{d^2x}{dt^2} + \frac{K'l^2}{I}\frac{(x-h)}{(h_0)} = 0 \ldots\ldots (7)$$

which is the equation of motion for the oscillograph for test specimens obeying Hooke's law with K' = a constant. Let $u = x - h$

Then

$$\frac{d^2u}{dt^2} + \frac{K'l^2}{Ih_0}u = 0 \ldots\ldots\ldots\ldots (8)$$

For this simple harmonic motion

$$f = \text{frequency} = \frac{1}{2\pi}\sqrt{\frac{K'l^2}{Ih_0}}$$

$$\text{so } K' = \frac{4\pi^2 h_0}{l^2} If^2 \ldots\ldots\ldots\ldots (9)$$

For standard test specimens $\frac{1}{2}$ in. by $\frac{3}{4}$ in. in diameter

$$K' = \frac{4\pi^2(0.50/12)}{(1.6/12)^2} If^2$$

$$= 92.5\, If^2 \text{ lb.}$$

The area of the test specimen, however, is 0.441 sq. in. so

$$K = \frac{92.5}{0.441} If^2 = 210\, If^2 \text{ psi.} \ldots\ldots (10)$$

The moment of inertia of the lever and the weights of the particular machine under discussion is given by:

$$I = 0.0813 + n \times 0.0307 \text{ slug ft.}^2 \ldots (11)$$

where n = the total number of weights used in a given test.

The frequency of vibration is calculated from the chart by dividing a whole number of cycles by the elapsed time in seconds.

Impact Energy and Resilience:

In the beginning of a dynamic test and at the instant the lever is released, the lever possesses its maximum potential energy by virtue of the elevation of the heavy end. As the weight falls, part of the potential energy is converted into heat in the test specimen due to internal friction and part is stored in the test specimen by elastic compression. At the point B on the first downward sweep of the oscillation record in Fig. 4(*a*) the lever is undergoing a reversal of direction and is momentarily stationary. Since this is the lowest point of the vibration the potential energy of the lever is a minimum. The vertical component of the line AB is an accurate measure of the energy of the impact. Suppose the vertical length of the line AB were 1.00 in. due to the impact of one weight on the end of the lever. Then the distance through which the weight has fallen is $\frac{10.0}{16.0} \times 1.00 = 0.625$ in. and the corresponding energy of impact is 0.625×1.41 lb. = 0.882 in-lb. The volume of the test specimen is $0.500 \times 0.441 = 0.2205$ cu. in. Hence, the energy of a single weight corresponding to a 1.00 in. vertical distance on the chart is $\frac{0.882}{0.2205} = 4.00$ in-lb. per cu. in. of vulcanizate. Hence energy transfer in fundamental units can be calculated from maximum and minimum points on the oscillogram by the simple formula:

$$\text{Energy} = 4n' \times \text{vertical distance in inches on oscillogram} \ldots\ldots\ldots (12)$$

where n' is the number of unbalanced weights on the heavy end of the lever.

It will be noted that every rising line on the chart represents return of potential energy to the lever. Hence percentage resilience may be determined by taking the ratio of the rebound height to the impact height. That is from Fig. 4(a)

$$\text{Percentage resilience} = \frac{BC}{AB} \times 100$$

Routine Measurements:

It is now possible to consider specific details of the test for the measurement of the following static and dynamic characteristics:

1. Static Characteristics

(*a*) Compression loading and unloading characteristics. Load is given in pounds per square inch, deflections in inches or per cent.

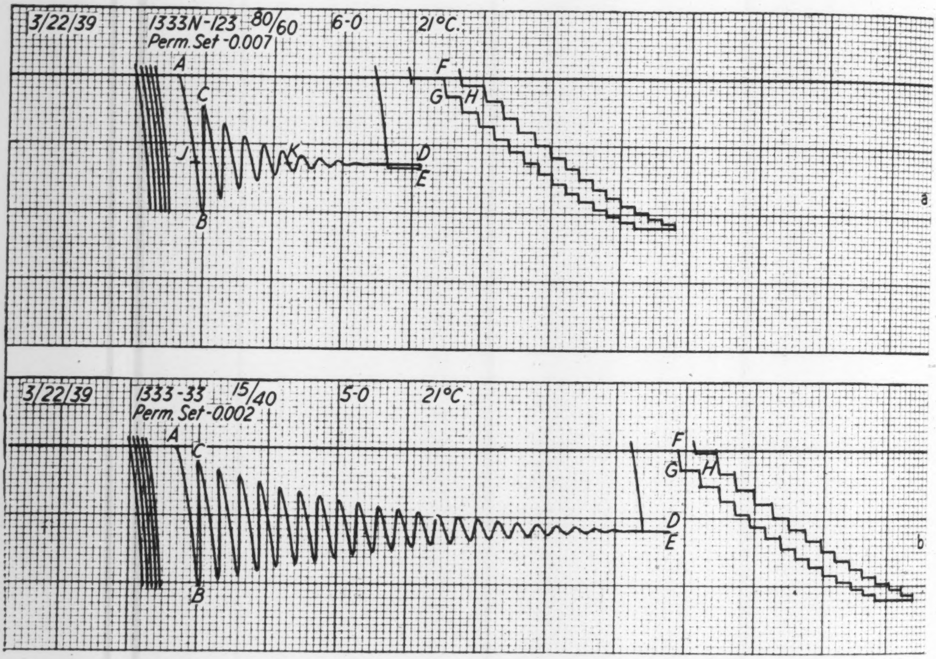

FIG. 4.—Typical Oscillograms for Neoprene (*a*) and Rubber (*b*).

(*b*) From the above data energy transfers may be calculated in inch-pounds, or inch-pounds per cubic inch of stock.

(*c*) Creep in inches or per cent under a given dead load (load range from 20 to 280 psi.).

(*d*) Set in inches or per cent.

2. Dynamic Characteristics

(*a*) Energy absorption of impact loads in inch pounds per cubic inch of stock.

(*b*) Percentage resilience under known load deflection range, and frequency.

(*c*) Effective dynamic modulus in pounds per square inch.

(*d*) A limited adjustment of the frequency of the test is possible.

Figures 4 and 5 illustrate the method of obtaining the data and converting it into customary forms. Figure 4(*a*) is the data sheet obtained from a neoprene type E compound (1) and Fig. 4(*b*) is a data sheet obtained for a similar rubber compound (2):

(1)	Neoprene type E	100.
	Extra light calcined magnesia	5.
	FF wood rosin	2.
	Phenyl-b-naphthylamine	2.
	Sulfur	1.
	Litharge	3.
	Press cure—80 min. at 141.7 C.	(287 F.)
	Durometer A hardness—41	
(2)	Smoked sheets	100.
	Zinc oxide	5.
	Stearic acid	1.
	Phenyl-alpha-naphthylamine	1.
	Tetra-methyl-thiuram-monosulfide	0.3
	Sulfur	3.
	Cure—15 min. at 152.8 C.	(307 F.)
	Durometer A hardness—39	

In Fig. 5 curves (*a*) and (*b*) are derived from the oscillograms shown in Fig. 4(*a*) and (*b*), respectively.

Referring to Fig. 4(*a*), the reference line is traced around the recording drum as the first step in any test. This is done with the heavy end of the lever held in the position corresponding to zero deformation of the test specimen by allowing the recorder drum to rotate through one revolution. Reproducible results are obtained only on test specimens which have been through several cycles of loading and unloading. For that reason, before beginning the oscillogram proper several complete sets of oscillations are run but are recorded only as arcs as shown on the left end of the oscillogram in Fig. 4(*a*). It will be seen that the lower end of each of these arcs can be compared with its predecessor to observe whether or not the same compression is being obtained on successive trials. It is, of course, necessary that the weights used for the conditioning cycles be the same as those to be used in the test. For the oscillogram of Fig. 4(*a*) six weights were used on the heavy end imposing an average load of 120 psi. on the test specimen.

With the heavy end in an elevated position, the motor drive was turned on and when the pen reached point *A* the hook was released and the oscillations recorded. After the oscillations were damped out and the record became a smooth line the drum was stopped and a vertical line was traced as the test specimen slowly compressed further under the load. The length of this line after any time interval is a measure of creep. At the end of two minutes the drum was rotated a short distance by hand to mark the end of the line *DE* and the heavy end of the lever was fastened in its original position by re-engaging the hook. Since creep had occurred the pellet no longer filled the distance between the two loading platforms. By turning the micrometer head, the upper platen was brought down to the new height of the pellet. The distance it moved was recorded as the set. In the test under discussion, this was recorded as 0.007 in. The creep which occurred during the same time interval of 2 min. was 0.006 in. There is no apparent reason why these two figures should check accurately, since one figure represents change in height under load and the other change in height of the unloaded pellet. After measuring the set

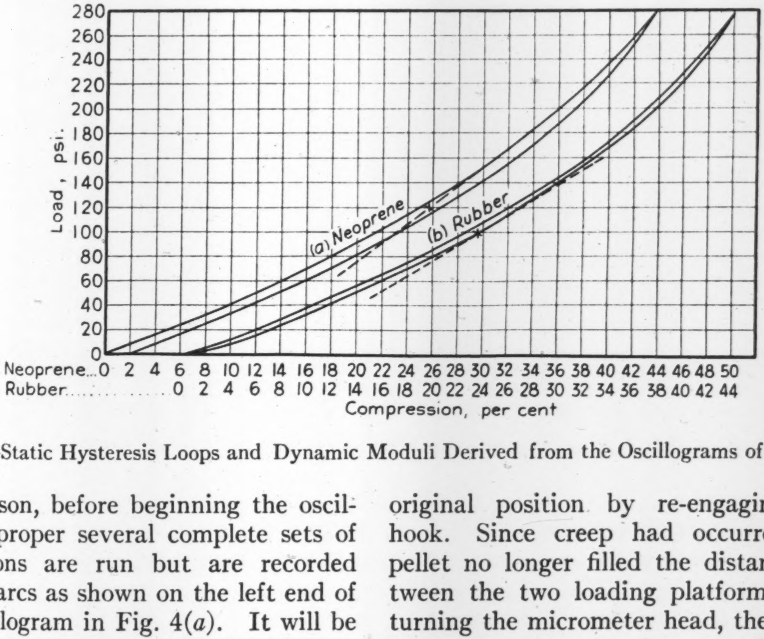

FIG. 5.—Static Hysteresis Loops and Dynamic Moduli Derived from the Oscillograms of Fig. 4.

the micrometer was returned to its former setting.

Measurements of creep and set over relatively short time intervals can be of only limited usefulness. A few comparisons between the short-time drift and drift over longer periods of time have indicated, however, that in a given class of compositions there may be a rough correlation between short-time drift and the total creep which would occur over longer periods of time. By plotting creep against time, curves of the type shown in Fig. 6 may be obtained.

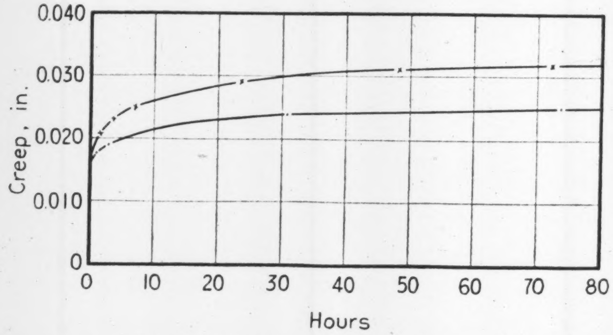

FIG. 6.—Creep Data Obtained on the Oscillograph for Two Neoprene Compositions Under 240 psi.

After completion of the creep test, the drum was then rotated so that the pen rested on point *F* and at this point all weights were removed from the machine. The hook was then held back and one weight was added to the pen end of the lever. Compression under the load of 20 psi. is represented on the chart (Fig. 4(*a*)) by the line *FG*, after which rotation of the drum by hand caused the line *GH* to be drawn. Weights were added stepwise in this way to the full load capacity of the machine, 280 psi. and were then removed one by one in order to obtain unloading data. The deflections corresponding to these loads were replotted on load compression axes to obtain the hysteresis loop shown in Fig. 5(*a*).

From the static loading and unloading curve thus obtained, it is possible to calculate the energy in inch pounds per cubic inch of stock required for compression to any desired extent. This is done by measuring the area under the curve up to the desired percentage of compression and expressing the area in terms of the quantities plotted on the axes. For example, one square on the curve sheet corresponds to a load of 20 psi. multiplied by a deflection of 2 per cent in a test specimen 1 in. high. The energy is, therefore, 20 by 0.02 or 0.4 in-lb. per cu. in. of stock. For a specific example, consider compression of 40.4 per cent on the curve of Fig. 5(*a*). The area under the loading curve up to this point gives an energy value of 41.4 in-lb. per cu. in.

Again referring to Fig. 4(*a*), the length of the line *AB* can be used to calculate the energy of the impact which caused the compression of 40.4 per cent. This calculation, based on Eq. 12, is 4 by 6 by 2.02 = 48.4 in-lb. per cu. in. of stock. If the static characteristics of this neoprene and its characteristics at the frequency of the dynamic test are the same, the impact energy should be the same as that previously calculated from the static load-compression curve. There is a discrepancy, however, and the dynamic energy is greater than that calculated from the static curve. The percentage resilience of the compound under these load conditions can be calculated from the ratio of the vertical heights of the lines *BC* and *AB*. This figure is 1.58 divided by 2.02 = 78.2 per cent. It should be noted, however, that this value of the resilience was determined for the compound at 21 C. at the stated load, deflection range and frequency; and that a change in one of the variables might change the resilience.

We now come to the calculation of effective modulus in pounds per square inch. The calculation of frequency in this case is based on 5 cycles and on elapsed time of 1.35 sec. so that $f = 5$ divided by $1.35 = 3.70$ cycles per second, where 1.35 is the distance *JK* in Fig. 4(*a*). Therefore, f^2 is 13.8 and from Eq. 11 $I = 0.0813 + 6 \times 0.0307 = 0.2655$ slug ft.^{2} Substituting in Eq. 10, $K = 210 \times 0.2655 \times 13.8 = 769$ psi. If the static and dynamic characteristics of neoprene were the same, this calculated value for the dynamic modulus should be numerically equal to the slope of the tangent drawn to the static load-compression curve shown in Fig. 5(*a*) at the load of 120 psi. For purposes of demonstration, however, it is more convenient to plot the value of *K* on the load-compression curve by drawing a straight line of the proper slope at the point corresponding to the point *D* in Fig. 4(*a*). At the point *D* the load is 120 psi. and the compression is 25.6 per cent. This point is indicated on Fig. 5(*a*) by the cross, and the dotted line represents the dynamic modulus. Here it can be seen that the effective dynamic modulus is greater than the static modulus represented by the slope of the load-compression curve at 120 psi.

The frequency of the test is determined by the value of *K* and the inertia of the machine. At a given load, *K* cannot be independently varied, but within a restricted range the inertia of the machine can be varied. For example, for the test of Fig. 4(*a*) there were six weights on one end of the machine and no weights on the other. The same load could have been obtained by using ten weights on one end of the machine and only four on the other. This would have increased the inertia of the machine and decreased the frequency of the test. For brevity, additional data are not given here. It appears, however, that a greater difference in frequency must usually be used than is possible by this method in order to measure the effect of test frequency upon the value of the dynamic modulus.

For simplicity the foregoing discussion has been based upon the test of neoprene illustrated in Fig. 4(*a*). It will be understood that the test is equally applicable to rubber and other rubber-like materials. For example, similar calculations can be made for the data in Fig. 4(*b*) for rubber. The static and dynamic moduli are illustrated in Fig. 5(*b*) and it is significant that they are within experimental error the same. In this respect, they differ from the results for neoprene. In further confirmation of the difference between the neoprene compound and the rubber compound, the energy values also correspond for the static and dynamic tests. The energy imparted to the rubber by the impact in Fig. 4(*b*) is $4 \times 5 \times 2.05 = 41.0$ in-lb. per cu. in. of stock. The area under the curve up to 41.0 per cent compression gives 40.4 in-lb. per cu. in. of stock. This also seems to be in almost perfect agreement with the value obtained from the dynamic test.

It is likely that the difference between static and dynamic characteristics are linked in some specific way with the damping factor of a given compound: that compounds having high resilience will show the least difference between static and dynamic characteristics and that the discrepancy between the two is in general widened as the resilience decreases. It is important to emphasize, however, that the value K is given as an effective dynamic modulus but not an actual physical modulus. It is in a sense a fictional quantity. Actually the oscillations do not occur over a linear load-compression relationship except for small deflections near zero load and for heavily reinforced compositions. However, the dynamic modulus is a quantity which has greater significance with respect to vibration calculations than any value that could be taken from the static curve.

Brevity requires that treatment of certain details be restricted to brief statements. The mathematical derivations, for example, have been confirmed by tests of a calibrated coil spring. With respect to the molded test specimens, the use of nominal rather than actual dimensions seems justified since mold shrinkage is characteristic of a given vulcanizate either in the preparation of test specimens or in the manufacture of articles in production. Test specimens can be prepared in other ways than molding as special circumstances may require. Slight errors in testing have been noticed due to frictional losses between the surface of the test specimen and the compressing platens. These errors may be eliminated by using test specimens adhered to metal end plates.

Conclusions:

The oscillograph described has been developed primarily as a laboratory instrument to evaluate rubber and neoprene compounds for mechanical applications. It is complete in itself as a means of measuring all of the quantities inherently involved in such service in units which are understandable to rubber technologists and mechanical engineers alike. It is hoped that it may serve its purpose by bringing into closer cooperation those who make and those who use rubber springs. The details of the test have been carefully developed and it is expected that the machine and standard test specimen described will not need essential modification for routine use. However, enough background has been given so that the machine may be modified in accordance with definite principles in order to gain greater load capacity if required. The test has been restricted thus far to compression. The author expects to adapt the machine to tests in shear, and by correlation between shear data and compression data to obtain figures capable of substitution in relationships already offered by other investigators[3,4,5,6] for calculations in the applications and design of rubber springs. This field of calculation is complicated and in an early state of development, but by the use of the oscillograph it should be easier to obtain the quantities of information required to clarify our understanding of the mechanical characteristics of rubber-like materials within the range of deformation encountered in structural use.

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[3] C. F. Hirshfeld and E. H. Piron, "Rubber Cushioning Devices," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 59, p. 471 (1937).

[4] E. H. Hull, "The Use of Rubber in Vibration Isolation," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 4, p. A109 (1937).

[5] J. F. D. Smith, "Rubber Mountings," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 5, p. A13 (1938).

[6] F. L. Haushalter, "The Mechanical Characteristics of Rubber," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 61, p. 149 (1939).

DISCUSSION

Mr. S. D. Gehman[1] *(presented in written form).*—The instrument is well suited for the purpose intended and should be particularly useful in the development of compounds. The test is comparatively simple, rapid, and accurate. The author has sufficiently realized and pointed out some of the limitations of the data, in regard to set and creep, for instance.

The test differs from most dynamic tests that have been described in that the oscillations are free rather than forced. In most mechanical applications of rubber the vibrations are forced. It would be worth while to know whether these two fundamentally different types of testing give corresponding results. The free vibration system is much simpler. The frequencies used for testing rubber under forced vibrations have usually been much higher than those in the present test but the evidence in the literature indicates that the dependence on frequency is not so very great.

The paper gives an incomplete impression in regard to the comparison of the dynamic and static moduli for rubber from the one example cited, for which the two moduli were found to be the same. Data published by other investigators seems to leave little question but that the dynamic modulus for some compounds is higher than the static value. Thus, Kosten[2] states that the ratio of the dynamic to the static modulus, as a rule, lies between 1 and 2. It is true that for some of his compounds the difference was very small.

Mr. Felix L. Yerzley.[3]—Mr. Gehman has raised a very interesting and important question. Both free and forced vibrations occur in various types of mounting service and it seems likely that tests under both sets of conditions should be conducted until our knowledge is sufficient to generalize from one condition to the other.

The examples chosen for the paper to illustrate the methods of calculation do not show the range of characteristics that different compositions may have. Data obtained for a variety of neoprene and rubber compounds seem to confirm the relative values of dynamic and static moduli as reported by Kosten.

Mr. H. A. Depew.[4]—I should like to ask Mr. Yerzley: first, what is the difference between forced and free vibration to which Mr. Gehman referred; and secondly, how does this test compare with the pendulum test that has been described by the Goodyear people and by Dunlop?

Mr. Yerzley.—Perhaps the easiest way to answer the first part of the question is to cite an example familiar to all of us. Consider an automotive support in which the normal speed of rotation of the engine may be as high as 4000 r.p.m. The frequency of forced oscillations would be as high as 8000 or 16,000 r.p.m., depending upon the number of cylinders in the engine. However, you may be familiar with the wide oscillations of an engine which is idling. In such a case there is a degree of resonance between the motor speed and the natural frequency of the motor on its mountings. The frequency at resonance is the starting point for the rational design of mountings, and a test in which free oscillations are observed should have definite value. This is particularly true because of the wide spread between the static characteristics and the dynamic characteristics of certain compositions.

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[1] Physicist, Research Dept., The Goodyear Tire and Rubber Co., Akron, Ohio.

[2] C. W. Kosten, "Static and Dynamic Properties of Rubber Under Compression," *Proceedings*, Rubber Technology Conference (London), p. 987 (1938).

[3] Physicist, Rubber Chemicals Division, Organic Chemicals Dept., E. I. du Pont de Nemours and Co., Inc., Wilmington, Del.

[4] Research Chemist, American Zinc Sales Co., Columbus, Ohio.

With respect to the second part of the question, it is significant that the resilience of rubber measured on the oscillograph may be as high as 95 per cent, while the resilience indicated by a pendulum test may be only 80 or 85 per cent.

MR. F. C. THORN.[5]—What means are employed to prevent slippage between the sample and the plate, which, of course, would introduce irreversible work?

MR. YERZLEY.—The loading surfaces are not lubricated, and we have found by test that in most cases the employment of means to prevent slippage is not really warranted. However, under special conditions, which I do not at the moment know how to specify, precautions should be taken either by using a roughened surface such as sandpaper on the platens, or by using test pieces adhered to metal end plates. A few tests have indicated that elimination of slippage may be expected to increase the apparent resilience by 1 or 2 per cent. On the other hand, intentional lubrication of the platens to increase slippage causes a pronounced decrease in resilience.

MR. J. J. ALLEN.[6]—Has any work been done on the use of this machine in relation to preloading? If you start with a $\frac{1}{2}$-in. thick sample, it would not be $\frac{1}{2}$ in. high at the high point of the curve after preloading, but some lesser thickness.

MR. YERZLEY.—That condition occurs in every test because the starting height and the successive heights at the high points of the curve are points of increasing compression.

MR. ARTHUR W. CARPENTER.[7]—I presume that Mr. Yerzley has considered the question of testing samples in what we ordinarily refer to as shear, although his discussion has dealt solely with compression. Shear is very important in the automotive field, and I am inquiring simply for information as to whether work has been done along this other line also.

MR. YERZLEY.—So far, tests have not been made in shear, but the machine is readily adaptable to shear, and I hope to do some work along that line in the not too distant future.

MR. R. S. HAVENHILL.[8]—I should like to ask Mr. Yerzley whether there is any appreciable temperature rise in the sample during this test, and if any work has been done at other than room temperature.

MR. YERZLEY.—Most of the work so far has been performed at room temperature. There have been a few tests of neoprene at elevated temperatures, which showed a slight increase in resilience and about the same modulus. In any given test the energy absorbed by the test specimen is inadequate to produce an appreciable temperature rise.

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[5] Chief Chemist, The Garlock Packing Co., Palmyra, N. Y.

[6] Chief Chemist, Mechanical Rubber Goods Division, The Firestone Tire and Rubber Co., Akron, Ohio.

[7] Manager of Testing Laboratories, The B. F. Goodrich Co., Akron, Ohio.

[8] Rubber Research Chemist, St. Joseph Lead Co., Monaca, Pa.

THE CALCULATION OF EQUILIBRIA IN DILUTE WATER SOLUTIONS

By D. S. McKinney[1]

Synopsis

The method of calculating the equilibrium concentrations of the constituents of water solutions from the equilibrium constants, the law of the conservation of matter and the principle of electrical neutrality is described. The use of the activity function is discussed, and the formulas for the calculation of the activity coefficients of ions from the Debye-Hückel equation are given. The effect of temperature on the equilibria is discussed. The formulas relating the equilibrium constants to other thermodynamic quantities such as the free energy, heats and entropies of reaction, and the electromotive force of cells are given.

The use of the various formulas is illustrated by examples selected from the field of corrosion or of water treatment.

During the past twenty years, the work of Lewis (**1**)[2] in applying the thermodynamics of Gibbs to chemical problems and the development of a reasonably accurate theory of electrolytes by Debye and Hückel (**2, 3**) have encouraged experimental work so that today there exists a great mass of data which can be used in many calculations of industrial interest. Even when the necessary data are not available, an understanding of the principles involved in the calculations will often indicate that a relatively simple measurement will allow the calculation of a result that is very difficult to measure directly. One purpose of this paper is to make the fundamental formulas and definitions available, in as brief a form as is possible, to the reader who has not followed the modern development of the theory, so that he may use the great mass of experimental data that has been accumulated.

The study of equilibria in solutions of electrolytes necessarily forms but a small part of the majority of courses in physical chemistry. In order to secure brevity, most of the problems are solved by making approximations suitable to the particular case under discussion but not applicable in general. The first purpose of this paper is to remind chemists of the fundamental principles which all equilibrium calculations must satisfy.

In order to avoid algebraic complications, the method will first be developed using concentrations in the equilibrium expressions. The activity function will then be discussed, and the equilibrium formulas modified to include activities.

Fundamental Principles Available for the Solution of Equilibrium Problems:

We first assume in agreement with the Debye-Hückel theory that all strong electrolytes are completely dissociated. The equations representing any system in equilibrium must satisfy the following three principles:

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[1] Assistant Professor of Chemistry, Carnegie Institute of Technology, Pittsburgh, Pa.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 1202.

I. All equilibria existing in the system must be satisfied.

II. No atoms are gained or lost in chemical reactions (the law of conservation of matter).

III. The sum of the charges on the ions in the system must be zero (the principle of electrical neutrality).

We shall first apply these principles to the relatively simple case of the hydrogen ion concentration of a solution of sodium acetate, whose concentration we take as m moles per liter. (All bracketed formulas in this paper indicate concentrations in moles per liter.)

Then from principle I, we write:

$$K_A = \frac{[H^+][Ac^-]}{[HAc]} \quad \ldots\ldots\ldots (1)$$

$$K_W = [H^+][OH^-] \ldots\ldots\ldots (2)$$

from principle II:

$$m = [Na^+] \ldots\ldots\ldots\ldots (3)$$

$$m = [Ac^-] + [HAc] \ldots\ldots (4)$$

from principle III:

$$[Na^+] + [H^+] = [OH^-] + [Ac^-] \,. (5)$$

We thus have five independent equations connecting the concentrations of the five molecular species present, from which we eliminate all but the H^+ ion concentration as follows:

Substituting Eq. 3 in Eq. 5 and solving the resulting equation for $[OH^-]$, and substituting this value in Eq. 2 gives:

$$K_W = [H^+]\left\{m + [H^+] - [Ac^-]\right\} . (6)$$

Eliminating [HAc] from Eqs. 1 and 4 gives:

$$K_A = \frac{[H^+][Ac^-]}{m - [Ac^-]}$$

Solving this equation for $[Ac^-]$ and substituting in Eq. 6 gives:

$$K_W = [H^+]\left\{m + [H^+] - \frac{mK_A}{[H^+] + K_A}\right\}$$

$$= [H^+]^2\left\{\frac{m}{[H^+] + K_A} + 1\right\} \ldots (7)$$

an equation which, although more difficult to solve, has the advantage over the ordinary hydrolysis equation in that it gives the correct H^+ ion concentration at low concentrations of sodium acetate, as is indicated by the following example. The usual approximate formula used for calculating the hydrolysis of a salt of this type is $\frac{K_W}{K_A} = \frac{[OH^-]^2}{m - [OH^-]}$, which is obtained by neglecting the OH^- ion produced by the dissociation of water. In neutral water $[H^+] = [OH^-] = 10^{-7}$. Taking $K_W = 10^{-14}$, $K_A = 1.8 \times 10^{-5}$ and $[OH^-] = 10^{-7}$, we calculate from the approximate formula that $m = 1.8 \times 10^{-5}$. Substituting this value of m in the accurate formula, Eq. 7, gives $[H^+] = 7.1 \times 10^{-8}$, as compared with 10^{-7} from the approximate formula, showing that the approximate formula is in error at this concentration by about 30 per cent for sodium acetate.

Equations obtained by the application of principles I, II, and III may always be solved by trial, regardless of their complexity. For example, we may find by trial the value of $[H^+]$ which makes the right hand side of Eq. 7 equal to K_W.

Polybasic Acids:

We will now turn to a more interesting and industrially important case, a solution of known pH containing a known amount of CO_2. From principle I:

$$K_1 = \frac{[H^+][HCO_3^-]}{[H_2CO_3]} \ldots\ldots (8)$$

$$K_2 = \frac{[H^+][CO_3^=]}{[HCO_3^-]} \quad \ldots\ldots\ (9)$$

$$K_W = [H^+][OH^-] \quad \ldots\ldots\ (10)$$

From principle II, if C = total moles of CO_2,

$$C = [H_2CO_3] + [HCO_3^-] + [CO_3^=] \quad \ldots\ldots\ (11)$$

From the definition for pH, $[H^+] = 10^{-pH}$
From principle III,

$$[H^+] - [OH^-] - [HCO_3^-] - 2[CO_3^=] = \text{const.} \quad \ldots\ldots\ (12)$$

where the constant is the sum of the charges on all the ions not involved in the equilibria. This last equation will not be employed until we consider the effect of temperature on the equilibrium concentrations. Excluding it for the present we see that, knowing the pH and the total CO_2, Eqs. 8, 9, 10, 11 and the equation of definition for pH may be solved for any desired ion concentration in a manner similar to that used in obtaining Eq. 7 for the hydrolysis of sodium acetate. This procedure would be used if only a few calculations are to be made. If many calculations must be made, the better procedure is as follows: Solve Eq. 9 for $[CO_3^=]$ and substitute in Eq. 11. Then solve Eq. 8 for $[HCO_3^-]$ and substitute in the equation resulting from substituting the $[CO_3^=]$ in Eq. 11 giving:

$$C = [H_2CO_3] + \frac{K_1}{[H^+]} \cdot [H_2CO_3] + \frac{K_1 \cdot K_2}{[H^+]^2} \cdot [H_2CO_3] \quad \ldots\ (13)$$

from which:

$$\frac{[H_2CO_3]}{C} = \frac{1}{1 + \dfrac{K_1}{[H^+]} + \dfrac{K_1 \cdot K_2}{[H^+]^2}} \quad \ldots\ (14)$$

(the fraction of the total CO_2 present as H_2CO_3 or free CO_2)

Similarly:

$$\frac{[HCO_3^-]}{C} = \frac{\dfrac{K_1}{[H^+]}}{1 + \dfrac{K_1}{[H^+]} + \dfrac{K_1 \cdot K_2}{[H^+]^2}} \quad \ldots\ (15)$$

$$\frac{[CO_3^=]}{C} = \frac{\dfrac{K_1 \cdot K_2}{[H^+]^2}}{1 + \dfrac{K_1}{[H^+]} + \dfrac{K_1 \cdot K_2}{[H^+]^2}} \quad \ldots\ (16)$$

Making use of the definition for pH we obtain,

$$\frac{[H_2CO_3]}{C} = \frac{1}{1 + K_1 \times 10^{pH} + K_1 \cdot K_2 \times 10^{2pH}} \quad \ldots\ldots\ (17)$$

$$\frac{[HCO_3^-]}{C} = \frac{K_1 \times 10^{pH}}{1 + K_1 \times 10^{pH} + K_1 \cdot K_2 \times 10^{2pH}} \quad \ldots\ (18)$$

$$\frac{[CO_3^=]}{C} = \frac{K_1 \cdot K_2 \cdot 10^{2pH}}{1 + K_1 \times 10^{pH} + K_1 \cdot K_2 \times 10^{2pH}} \quad \ldots\ldots\ (19)$$

$$[H^+] = 10^{-pH} \quad \ldots\ldots\ (20)$$

$$[OH^-] = K_W \times 10^{pH} \quad \ldots\ (21)$$

A table or plot of $[H^+]$, $[OH^-]$, and the fraction of the total CO_2 present as each molecular species is then made using the pH as the independent variable in Eqs. 17 to 21. From the plot or table, the concentrations of $[H^+]$ and $[OH^-]$ may be read directly. The concentration of each molecular species containing CO_2 is easily obtained by reading from the plot the fraction present at the known pH and multiplying this value by the total CO_2 concentration.

The method outlined was proposed in a paper by the author (4) and is embodied in the tentative methods of water analysis published by the Society in

1938.[3,4] Its extension to other substances such as SO_2, H_2S, H_3PO_4, and NH_4OH is obvious. The paper mentioned fully describes the method to be used when the solution contains both CO_2 and orthophosphates.

Such tables are very useful in calculating the solubility of relatively insoluble salts from their solubility product constants when the negative ion of the salt is involved in the equilibria existing in the system. For example, if one wishes to calculate the residual calcium after treatment with soda ash or an orthophosphate, one should know the pH value and the total CO_2 or phosphate present. From the table or graph the concentration of $[CO_3^{=}]$ or $[PO_4^{\equiv}]$ is calculated and the resulting value substituted in the solubility product expression. At 25 C. and pH = 10, only 35 per cent of the CO_2 is in the form of $CO_3^{=}$ ion and only 0.36 per cent of the orthophosphate in the form of $PO_4^{\equiv}$ ion (4). Making use of the solubility product for $Ca_3(PO_4)_2$, $L = [Ca^{++}]^3[PO_4^{\equiv}]^2$. Let the total phosphate $= P$. Then on assuming that all the phosphate is present as $PO_4^{\equiv}$, we have $L = [Ca^{++}]_1^3 \cdot P^2$, whereas the substitution $PO_4^{\equiv} = 0.0036P$ gives $L = [Ca^{++}]_2^3 \cdot (0.0036)^2 P^2$. Equating these two expressions and solving for the ratio $[Ca^{++}]_2/[Ca^{++}]_1$

$$\frac{[Ca^{++}]_2}{[Ca^{++}]_1} = \frac{1}{(0.0036)^{2/3}} = 43$$

Thus, one finds that the concentration of Ca^{++} ion remaining in solution is 43 times the value found if the total phosphate is used in the solubility product expression.

The Activity Function and the Debye-Hückel Equation:

The Arrhenius theory of electrolytic dissociation, proposed in 1887, was able to explain quantitatively the behavior of weak electrolytes when present alone in solution. Results calculated by applying this theory to mixtures of weak and strong electrolytes or to strong electrolytes alone were only qualitatively correct. In order to secure quantitative agreement, it would be necessary to assume that equilibrium constants and solubility products varied with the concentration of the solution.

Little progress was made in the treatment of strong electrolytes until 1921 when Lewis and Randall (1) proposed that a new function, the activity, be used in place of the concentration in all equilibrium expressions. This proposal would have been of little practical value had they not, at the same time, discovered that: "In dilute solutions, the activity coefficient of a given ion is the same in all solutions of the same ionic strength." The activity function (for a solute in solution) has the following properties. At infinite dilution, activity equals the concentration. This assumption is necessary since the Arrhenius theory explains quantitatively the behavior of weak electrolytes in solution (that is, the ion concentration is very low). At high ion concentrations, the activity must take on such values that the equilibrium constants do not vary with concentration. For pure solids or liquids, the activity is arbitrarily set equal to one. For perfect gases, the activity is equal to the pressure in atmospheres. The relation between concentration and activity for solutes is given by the equation:

$$a = \gamma c$$

where a = activity,

γ = activity coefficient, and

c = concentration (molarity)

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[3] Tentative Method for Determination of Total Carbon Dioxide and Calculation of the Carbonate and Bicarbonate Ions in Industrial Waters (D 513 - 38 T), *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1277 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1595.

[4] Tentative Method for Determination of the Total Orthophosphate and Calculation of the Respective Orthophosphate Ions in Industrial Waters (D 515 - 38 T), *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1283 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1601.

The ionic strength (μ) is defined by the equation:

$$\mu = \frac{\sum_i c_i \nu_i^2}{2}$$

where μ = ionic strength
c_i = concentration of ith ion (molarity)
ν_i = valence of ith ion

and the expression is summed over all ions in solution. The calculation of the ionic strength is best illustrated by an example. Consider a solution which contains NaCl, $Fe_2(SO_4)_3$ and Na_2SO_4 each at 0.01 moles per liter. The ion concentrations will then be $[Na^+] = 0.03$; $[Fe^{+++}] = 0.02$; $[SO_4^=] = 0.04$ and $[Cl^-] = 0.01$ moles per liter.

$$\mu = \frac{\sum_i c_i \nu_i^2}{2}$$

$$= \frac{[Na^+]\cdot 1^2 + [Fe^{+++}]\cdot 3^2 + [SO_4^=]\cdot 2^2 + [Cl^-]\cdot 1^2}{2}$$

$$= \frac{0.03 + 0.02 \times 9 + 0.04 \times 4 + 0.01}{2}$$

$$= 0.19$$

A table of ion activity coefficients *versus* ionic strength is given by Lewis and Randall (1).

It will be recognized that the work of Lewis and Randall represented a considerable advance, since previous to their work it was necessary to measure activities in every solution which might be met in practice. After the discovery of the relation of activity to ionic strength it was necessary, if solutions were dilute, to measure the activity of a given substance in the presence of one added salt. One was then assured that the activity coefficient of the substance would be the same, regardless of the added electrolyte, so long as the ionic strength remained the same.

In 1923 Debye and Hückel (2, 3) were able to derive an equation for the activity coefficient of an ion, which has since been confirmed experimentally by many investigators. Whereas the Arrhenius theory assumed that the ions behaved like neutral molecules and that the behavior of electrolytes was due to their partial dissociation into ions, Debye and Hückel assumed that all strong electrolytes were completely ionized and that their deviation from ideal behavior was due to the electrostatic forces between the ions. The simplest form of their equation, which is valid in dilute solution, is:

$$\log \gamma_i = -\frac{A}{(DT)^{\frac{3}{2}}} \cdot \nu_i^2 \sqrt{\mu};$$

$$A = \frac{\epsilon^3 N}{2kR^{\frac{1}{2}}} \sqrt{\frac{8\pi}{1000}}$$

where D = dielectric constant of the solvent,
T = absolute temperature (deg. Kelvin),
ϵ = charge on the electron,
N = Avogadro's number,
k = Boltzmann's constant, and
R = gas constant = $k \cdot N$,

the remaining symbols having the same significance as before. It will be seen that A is made up of universal constants. Inserting their values into the expression for A gives: $A = 1.815 \times 10^6$. For water, $D = 88.00$ at 0 C. and 78.54 at 25 C. so that the equation becomes:

$$\log \gamma_i = -0.4872\nu_i^2\sqrt{\mu} \text{ at } 0\text{ C., or}$$
$$\log \gamma_i = -0.5066\nu_i^2\sqrt{\mu} \text{ at } 25\text{ C.}$$

From the data of Wyman (5),

$$D = 78.54\left\{1 - 0.00460(t - 25) + 0.0000088(t - 25)^2\right\}$$

where t is the temperature in degrees Centigrade, and D represents the dielectric constant of water from 0 to 150 C.

within experimental error. The proper value of D for any temperature desired in this range may thus be calculated and inserted in the above equation.

The more complete forms of the Debye-Hückel equation contain constants which depend on the molecular species present and which must be determined experimentally. In calculations on water analysis, the solutions are usually sufficiently dilute that the simple equation above gives results as accurate as the data available for making the calculations. Until more accurate data (6) (equilibrium constants and the like) and more accurate experimental methods are available, nothing is gained by the use of a more complicated equation.

We are now ready to correct the equations derived in the first part of the paper so as to comply with modern ideas. Taking the first example, the hydrolysis of sodium acetate, we see that we should write in place of Eqs. 1 and 2:

$$K_A = \frac{a_{\mathrm{H}^+} \cdot a_{\mathrm{Ac}^-}}{a_{\mathrm{HAc}}} \quad \ldots\ldots\ldots (1')$$

and

$$K_W = a_{\mathrm{H}^+} \cdot a_{\mathrm{OH}^-} \ldots\ldots\ldots (2')$$

Introducing activity coefficients,

$$K_A = \frac{[\mathrm{H}^+][\mathrm{AC}^-]}{[\mathrm{HAC}]} \cdot \frac{\gamma_{\mathrm{H}^+} \cdot \gamma_{\mathrm{Ac}^-}}{\gamma_{\mathrm{HAc}}}$$

and

$$K_W = [\mathrm{H}^+][\mathrm{OH}^-]\gamma_{\mathrm{H}^+} \cdot \gamma_{\mathrm{OH}^-}$$

Placing the activity coefficients with the equilibrium constants,

$$\frac{K_\mathrm{A} \cdot \gamma_{\mathrm{HAc}}}{\gamma_{\mathrm{H}^+} \cdot \gamma_{\mathrm{Ac}^-}} = \frac{[\mathrm{H}^+][\mathrm{AC}^-]}{[\mathrm{HAc}]} \quad \ldots (1'')$$

and

$$\frac{K_W}{\gamma_{\mathrm{H}^+} \cdot \gamma_{\mathrm{OH}^-}} = [\mathrm{H}^+][\mathrm{OH}^-] \ldots (2'')$$

The right-hand side of each of these equations is now identical with Eqs. 1 and 2 and our solution will be the same as before except that K_A and K_W of Eq. 7 must be replaced by the left-hand side side of Eqs. 1″ and 2″, respectively. Our equation then becomes

$$\frac{K_W}{\gamma_{\mathrm{H}^+} \cdot \gamma_{\mathrm{OH}^-}} = [\mathrm{H}^+]^2 \left\{ \frac{m}{[\mathrm{H}^+] + \dfrac{K_A \cdot \gamma_{\mathrm{HAc}}}{\gamma_{\mathrm{H}^+} \cdot \gamma_{\mathrm{Ac}^-}}} + 1 \right\} \ldots (7')$$

It should be noted at this point that in terms of activities, the

$$\mathrm{pH} = \log \frac{1}{a_{\mathrm{H}^+}} = \log \frac{1}{[\mathrm{H}^+] \cdot \gamma_{\mathrm{H}^+}}, \text{ or}$$

$$a_{\mathrm{H}^+} = \gamma_{\mathrm{H}^+} \cdot [\mathrm{H}^+] = 10^{-\mathrm{pH}} \ldots (20')$$

which replaces Eq. 20. Similarly, in the example on the carbonate equilibrium, the three fractions calculated, namely $\frac{[\mathrm{H_2CO_3}]}{C}$, $\frac{[\mathrm{HCO_3}^-]}{C}$, and $\frac{[\mathrm{CO_3}^=]}{C}$ (Eqs. 17, 18, and 19) should be replaced by $\frac{a_{\mathrm{H_2CO_3}}}{a_c}$, $\frac{a_{\mathrm{HCO_3}^-}}{a_c}$, and $\frac{a_{\mathrm{CO_3}^=}}{a_c}$ where a_c means the sum of the activities of $\mathrm{H_2CO_3}$, $\mathrm{HCO_3}^-$ and $\mathrm{CO_3}^=$.

Very few activity coefficients have been determined for uncharged molecules in solution. However, it is known that they fall off much less rapidly with increase in ionic strength than do the ionic activity coefficients. In dilute solutions, therefore, satisfactory results will be obtained if the activity coefficients of uncharged molecules are assumed to be unity.

These ideas are applied as follows, using a method of successive approximations:

1. The problem is solved assuming

that the activity coefficients are each equal to one. (This is equivalent to assuming that concentrations and activities are identical.)

2. The resulting distribution of ions involved in the equilibrium may be considerably in error but is usually accurate enough for the calculation of the ionic strength.

3. From the ionic strength so calculated, the activity coefficients may be calculated using the Debye-Hückel equation.

4. The activity coefficients are then inserted in the equations and the concentrations recalculated. These concentrations will be more nearly correct than those obtained in Step (1). The ionic strength is then recalculated using the new concentrations. If the result differs appreciably from the result of (2) above, the process is repeated until no further appreciable change occurs.

The application to the case of the carbonate equilibrium is described and illustrated in the paper "Interpretation of Water Analysis" referred to above. It should be noted that the ionic strength used in that paper is twice the ionic strength as defined herein. The latter definition is that used by Lewis and in general use in present-day literature.

Effect of Temperature on Equilibria:

Relatively few ionic equilibria have been studied at higher than room temperature. However, in many cases, the heat of reaction at 25 C. is known. We may then employ van't Hoff's equation to calculate the equilibrium constants at other temperatures:

$$\frac{d \log_e K}{dT} = \frac{\Delta H}{RT^2}, \text{ or}$$

$$\frac{d \log_e K}{d\left(\frac{1}{T}\right)} = -\frac{\Delta H}{R}$$

where $\log_e K$ is the natural logarithm of the equilibrium constant, and ΔH is the heat of reaction in calories. It should be noted that a negative value for ΔH means that the system loses heat, that is, that the reaction is exothermic.

If no other data exist, one can only hope that ΔH does not vary much with temperature. Assuming it constant,

$$\int_{K_1}^{K_T} d \log_e K = -\frac{\Delta H}{R} \int_{T_1}^{T} d\left(\frac{1}{T}\right)$$

whence

$$\log_e \frac{K_T}{K_1} = -\frac{\Delta H}{R}\left(\frac{1}{T} - \frac{1}{T_1}\right)$$

Usually, K and ΔH are tabulated at 25 C. (298.1 Kelvin). Assuming ΔH, T_1 and K_1 refer to the quantities at 298.1 Kelvin, changing from natural logs to $\log_{10}$ and inserting the value of R gives:

$$\log_{10} \frac{K_T}{K_{298.1}} = \frac{\Delta H_{298.1}}{4.58}\left(\frac{1}{298.1} - \frac{1}{T}\right)$$

from which K_T, the constant at absolute temperature T, may be calculated. The cases in which ΔH for ionic reactions is known as a function of temperature are very few. The reader is therefore referred to Lewis and Randall (1), for a more complete consideration of this problem.

The values of K_T thus calculated may, in the case of a simple problem like the hydrolysis of sodium acetate, be inserted in the equations obtained by application of principle I and solved as outlined above, remembering that the activity coefficients must be calculated from the Debye-Hückel equation containing the appropriate values of D and T.

K_W, the dissociation constant for water, has been determined over a wide range of temperatures. The values are tabulated in a paper, by Amorosi and McDermet (7).

For polybasic acids, a new table or graph of the activity fractions is constructed for the desired temperature, using the dissociation constants calculated as above. Referring to the CO_2 problem, it will be remembered that we have not used the equation of electrical neutrality (Eq. 12), $[H^+] - [OH^-] - [HCO_3^-] - 2[CO_3^=] = \text{const.} = G$. Considering first the case when the total volume of water is not changed, for example in a closed heater, the constant G will not change, since it represents the sum of the charges on the ions not involved in the equilibrium. Both the distribution and quantity of CO_2 present may change with increase of temperature. If the total CO_2 present at the higher temperature is measured, one may find, by trial, the pH at the higher temperature which satisfies the equation of electrical neutrality with the known value of G determined at room temperature. The pH thus found also gives the distribution of CO_2 between its various forms and the H^+ and OH^- concentrations. When the total volume of water changes, due either to evaporation or dilution with pure water, for example by condensation of steam, the change in G may be calculated from the equation $G_1V_1 = G_2V_2$ where G_1 and V_1 refer to the original condition and G_2 and V_2 to the final condition. Hence, to calculate G for the final state one need know only the ratio of the initial to the final volumes. We may then calculate from analyses made at room temperature the complete analysis as it would be at the higher temperature. The method will be fully illustrated by applying it to the CO_2 equilibrium in the paper referred to above, by Amorosi and McDermet.

Calculation of Equilibrium Constants from Other Data:

The equilibrium constants, for the reactions considered thus far, are available in the literature. In many cases to which the reader may wish to apply the methods considered, the equilibrium constants are not calculated, but other data are given from which they may be obtained.

Free Energy:

One such quantity is the free energy. The standard free energy change (ΔF°) for a reaction is related to the equilibrium constant by the equation $\Delta F^\circ = -RT \log_e K = -4.5787\ T \log_{10} K$.

To illustrate the use of this function, let us consider the question as to whether CO_2 in dry or superheated steam can be responsible for the corrosion noted in steam lines. If the CO_2 is to be responsible for any considerable corrosion, it must dissociate, producing O_2 at a pressure comparable to that produced by the water vapor, that is, the following two reactions must produce practically the same partial pressure of oxygen:

$$CO_2 \rightarrow CO + \tfrac{1}{2}O_2$$

$$H_2O \rightarrow H_2 + \tfrac{1}{2}O_2$$

$$K_{CO_2} = \frac{P_{CO} \cdot P_{O_2}^{1/2}}{P_{CO_2}}$$

$$K_{H_2O} = \frac{P_{H_2} \cdot P_{O_2}^{1/2}}{P_{H_2O}}$$

or

$$\frac{K_{CO_2}}{K_{H_2O}} = \frac{P_{CO} \cdot P_{O_2}^{1/2}}{P_{CO_2}} \cdot \frac{P_{H_2O}}{P_{H_2} \cdot P_{O_2}^{1/2}} = \frac{P_{CO} \cdot P_{H_2O}}{P_{CO_2} \cdot P_{H_2}}$$

if it is assumed that the pressure of O_2 is the same from the two reactions. We note that $\frac{K_{CO_2}}{K_{H_2O}} = K$ for the water gas reaction

$$CO_2 + H_2 \rightarrow CO + H_2O;$$

$$K = \frac{P_{CO} \cdot P_{H_2O}}{P_{CO_2} \cdot P_{H_2}}$$

and further, if we start with pure H_2O and CO_2 and produce equal quantities of O_2, then $P_{H_2} = P_{CO}$. Hence,

$$K = \frac{P_{H_2O}}{P_{CO_2}}$$

From the International Critical Tables, (8) we obtain for the water gas reaction

$$\Delta F^\circ = 10{,}100 - 1.81\,T \log_e T + 0.00445T^2 - 0.00000068T^3 - 0.54T$$

At 125C. (398.1 Kelvin) we obtain by substitution in this equation $\Delta F^\circ_{398.1} =$ 6448 cal., and at 425 C. (698.1 Kelvin) $\Delta F^\circ_{698.1} =$ 3757 cal. Substituting in the equation, $\log_{10} K = \dfrac{-\Delta F^\circ}{4.5787T}$, $K_{398.1} = 10^{-3.54}$ and $K_{698.1} = 10^{-1.18}$ From which, referring to the equation $K = \dfrac{P_{H_2O}}{P_{CO_2}}$, we see that to produce the same pressure of O_2 from CO_2 and water vapor $P_{CO_2} = 3470 \cdot P_{H_2O}$ at 125 C. and $P_{CO_2} = 14.8 \cdot P_{H_2O}$ at 425 C. which embraces the range of temperature usually met with in steam practice. Steam seldom contains more than 100 p.p.m. of CO_2 from which, since the partial pressures are proportional to the moles of material present, $P_{CO_2} = \dfrac{100}{44} \times \dfrac{18}{10^6} P_{H_2O} = 4.1 \times 10^{-5} P_{H_2O}$. Comparing this value for the pressure of CO_2 with that calculated from the water gas reaction, we see that at 125 C. the CO_2 actually found in practice is $\dfrac{4.1 \times 10^{-5}}{3470} = 1.2 \times 10^{-8}$ times that required to produce an oxygen pressure equal to that of the steam. At 425 C. the corresponding figure is $\dfrac{4.1 \times 10^{-5}}{14.8} = 2.8 \times 10^{-6}$. If the CO_2 is to produce appreciable corrosion, these figures must be at least of the order of unity. We must, therefore, conclude that the CO_2 is not responsible for the corrosion in dry or superheated steam.

Free Energy and Heats of Reaction from Free Energies and Heats of Formation:

In some cases, free energies or heats of reaction are not given for the reaction desired, but the corresponding free energies and heats of formation of the various compounds entering into the reaction are given, generally in calories per mole. The standard free energy for the reaction is then found by adding the free energies of formation of products, each multiplied by the number of moles in the balanced equation, from which is subtracted the similarly multiplied sum of the free energies of formation of reactants. For example, for the reaction:

$$\begin{array}{llll} C_2H_2(g) & + \; 3O_2(g) & \rightarrow 2CO_2(g) & + \; H_2O(l) \\ +\,50{,}750 & + \; 0 & 2(-94{,}450) & \\ & & & + \; (-56{,}690) \end{array}$$

$$\Delta F^\circ = 2(-94{,}450) + (-56{,}690) - 50{,}750 = -296{,}340 \text{ cal.}$$

The heat of reaction, ΔH, is calculated in exactly the same way from the heats of formation. It should be noted that both free energies and heats of formation of the elements are taken as zero when the elements are in their standard state. The standard state of an element is taken as that form of the element which is most stable at room temperature and at a pressure of one atmosphere. In assigning free energies and heats of formation to ions, it is necessary to fix the values for one ion arbitrarily. The value zero is therefore assigned to the H^+ ion at unit activity for both quantities. The heat of reaction (or of formation) when known at various temperatures may be expressed as a function of temperature, usually as a power series, that is,

$$\Delta H = \Delta H_o + \Delta\Gamma_o\,T + \tfrac{1}{2}\Delta\Gamma_1\,T^2 + \tfrac{1}{3}\Delta\Gamma_2 T^3 \ldots\ldots$$

where the terms $\Delta\Gamma$ come from the equation for change in the molal heat capacity at constant pressure.

$$\Delta C_p = \Delta\Gamma_o + \Delta\Gamma_1 T + \Delta\Gamma_2 T^2 \ldots\ldots\ldots\ldots$$

ΔC_p is calculated from the molal heat capacities, C_p, of the substances involved in the reaction in exactly the same way as $\Delta F°$ and ΔH.

Relation of Free Energy to the Heat Content and Entropy:

The free energies and heats of reaction are connected by the equation $\Delta F = \Delta H - T\Delta S$, where ΔF = free energy, ΔH = heat of reaction and ΔS = change in entropy. It will be noted that if any two of these quantities are known, the third may be calculated.

The absolute entropy of a substance may be evaluated from specific heat measurements, using the third law of thermodynamics, or may be calculated from spectral data. The entropy change for a reaction may then be obtained from the absolute entropies of the substances involved, in the same way that the free energy change for a reaction is obtained from the free energies of formation. A very excellent summary of data so obtained has been prepared by Kelley (9)

Equilibrium Constants and Free Energies from the Electromotive Force of Cells:

Many reactions have been investigated by studying the voltage of galvanic cells in which the reaction is carried out. The standard voltage ($E°$) of these cells is related to the equilibrium constant and the standard free energy change of the cell reaction by the equations

$$E° = \frac{RT}{n\mathscr{F}} \log_e K$$

$$-n\mathscr{F}E° = \Delta F°$$

where $E°$ = voltage of the cell when all reacting substances are at unit activity,
R = gas constant,
n = the number of Faradays of electricity which would flow through the cell to accomplish the reaction written, and
$\mathscr{F}$ = 96,494 = the number of coulombs per Faraday

Changing to logarithms to the base 10 and introducing the values of R and $\mathscr{F}$

$$E° = 0.00019844 \frac{T}{n} \log_{10} K$$

$$E° = \frac{0.05915}{n} \log_{10} K$$

at 298.1 Kelvin (25 C.) at which temperature most values of $E°$ have been determined.

A table of $E°$ values for every possible cell reaction would be of tremendous length (45 cells may be constructed using 10 electrodes and 190 cells from 20 electrodes). It is evident then that tables of $E°$ values will be less cumbersome and therefore more usable if a value of $E°$ can be assigned to each electrode reaction, from which the voltage for any cell, made by combining two electrodes, may be calculated. Since electrodes are always used in pairs to form cells, we may arbitrarily define the $E°$ (single electrode potential) for one electrode reaction and measure the single electrode potentials of all other electrodes relative to the value so defined. By definition then, for the electrode reaction H_2(g, 1 atm) $\rightarrow 2H^+(a = 1) + 2e$, $E° = 0$ at all temperatures. The single electrode potential of any other electrode is then defined as the potential of the cell formed by combining the electrode in question with a standard hydrogen electrode, all substances involved in the cell reaction being in their standard states, that is, at unit activity.

Consider the reaction:

$$\text{Zn} + \text{Cu}^{++}(a = 1) \rightarrow \text{Zn}^{++}(a = 1) + \text{Cu};\ \Delta F°, E°$$

Let the free energy change for this reaction be ΔF° and the standard potential E°.

We may attain the same result in two steps by the reactions

$$Zn + 2H^+(a = 1) \rightarrow Zn^{++}(a = 1) + H_2(g, 1\ \text{atm});\ \Delta F^\circ_1,\ E^\circ_1$$

$$H_2(g, 1\ \text{atm}) + Cu^{++}\ (a = 1) \rightarrow 2H^+ (a = 1) + Cu;\ \Delta F^\circ_2,\ E^\circ_2$$

with free energy changes ΔF°_1 and ΔF°_2, and standard potentials E°_1 and E°_2 respectively. From the definition of single electrode potential given above, it will be noted that E°_1 is the single electrode potential for zinc and E°_2 is the negative of the single electrode potential for copper.

The free energy change of a reaction is the maximum energy which can be obtained from the reaction at constant pressure. Hence, $\Delta F^\circ = \Delta F^\circ_1 + \Delta F^\circ_2$; for if, for example, ΔF° were greater than $\Delta F^\circ_1 + \Delta F^\circ_2$, the energy from the first reaction would be more than sufficient to run the remaining reactions backward, thus obtaining energy without consuming any material. This possibility is denied by the law of conservation of energy.

Substituting, $\Delta F^\circ = -nE^\circ\mathcal{F}$ into the relation $\Delta F^\circ = \Delta F^\circ_1 + \Delta F^\circ_2$ and changing sign, we have $nE^\circ\mathcal{F} = nE^\circ_1\mathcal{F} + nE^\circ_2\mathcal{F}$. Since $\mathcal{F}$ is a constant and n has the same value, namely 2, for each reaction, we obtain:

$$E^\circ = E^\circ_1 + E^\circ_2$$

Thus we have proved that the standard potential for any cell reaction may be calculated by adding algebraically the single electrode potentials of the electrode reactions used in making the cell.

Since the single electrode potential is always measured relative to the standard hydrogen electrode, it is unnecessary to include the latter in our formulation. The cell reaction considered above would then be formulated as follows:

	Single Electrode Potential	
$Zn \rightarrow Zn^{++} + 2e$	+0.762	
$Cu^{++} + 2e \rightarrow Cu$	+0.345	(negative of value tabulated)
$Zn + Cu^{++} \rightarrow Zn^{++} + Cu$	1.107	= E° (standard potential for the cell)

The tables of single electrode potentials are constructed writing all half reactions as oxidations. When the complete reaction is formulated from two half reactions, one of the latter must of course be written as a reduction and will then be the reverse of one of the half reactions given in the table. When it is necessary to reverse a half reaction, the sign of the single electrode potential is changed. If it is necessary to use a multiple of a half reaction, the value of the single electrode potential remains constant.

It will be more interesting to apply these principles to the fundamental reaction for the corrosion of iron:

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2$$

We find tabulated (10) the following half reactions, which when added together give the reaction desired:

	Single Electrode Potential
$Fe + 2OH^- \rightarrow Fe(OH)_2 + 2e$	+0.877
$2e + 2H_2O \rightarrow 2OH^- + H_2$	−0.828
$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2$	$E^\circ = 0.049$

Substituting in the equation

$$E^\circ = \frac{0.05915}{n} \log K$$

$$0.049 = \frac{0.05915}{2} \log K$$

from which $K = 10^{1.66} = 45.7$. From this value of K it is evident that the corrosion of iron by water is spontaneous under most conditions under which iron is used, even in the absence of oxygen.

Some Data of Interest to Water Chemists:

A brief table of the constants relating to a few substances of interest to water chemists is given below for use in connection with the various types of calculations outlined:

DISSOCIATION (IONIZATION) CONSTANTS (10, 11) AT 25 C. (298.1 Kelvin).

	K_1	K_2	K_3
H_2S	1.15×10^{-7}	10^{-15}	......
H_2SO_3	1.2×10^{-2}	10^{-7}	......
H_3PO_4	7.5×10^{-3}	6.2×10^{-8}	10^{-12}
H_2CO_3	4.31×10^{-7}	4.70×10^{-11}	......
NH_4OH	1.81×10^{-5}	......	......
H_2O	$K_W = 1.008 \times 10^{-14}$	......	......

SOLUBILITY PRODUCT CONSTANTS (10, 11) AT 25 C.

$Ca(OH)_2 = 7.9 \times 10^{-6}$
$CaCO_3 = 4.82 \times 10^{-9}$
$Ca_3(PO_4)_2 = 10^{-25}$
$CaSO_4 \cdot 2H_2O = 2.4 \times 10^{-5}$
$Fe(OH)_2 = 1.65 \times 10^{-15}$
$FeCO_3 = 2.11 \times 10^{-11}$
$Fe(OH)_3 = 4 \times 10^{-38}$
$Cu(OH)_2 = 5.6 \times 10^{-20}$

STANDARD FREE ENERGIES AND ENTROPIES AT 25 C. (10, 11)

	$\Delta F°$ (cal.)	S
Ca^{++}	−132 700	+11.4
Fe^{++}	−20 310	−25.9
Fe^{+++}	−2 530	−63.3
Cu^{++}	+15 910	−26.5
$SO_4^{=}$	−176 100	+4.4
$H_2S(aq)$	−6 520	+29.4
HS^-	+2 950	+14.9
$S^{=}$	+23 420	−5.5
$H_2SO_3(aq)$	−128 535	+54.7
HSO_3^-	−125 905	+32.6
$SO_3^{=}$	−116 400	+3
$H_3PO_4(aq)$	−270 000	+44.0
$H_2PO_4^-$	−267 100	+28.0
$HPO_4^{=}$	−257 270	−2.3
$PO_4^{\equiv}$	−240 970	−45.0
$H_2CO_3(aq)$	−149 170	+45.1
HCO_3^-	−140 490	+22.2
$CO_3^{=}$	−126 390	−13.0
$NH_4OH(aq)$	−62 990	+42.4
NH_4^+	−18 960	+26.4
OH^-	−37 585	−2.49
H^+	0	0

References:

A paper such as this would be incomplete without a short list of books, wherein the interested person may obtain additional data or a more complete discussion of the problems involved in equilibrium calculations. G. N. Lewis and M. Randall (1) have fully discussed the application of thermodynamics to chemical problems. Latimer (10) and Latimer, Pitzer and Smith (11) have examined a great mass of data on the properties of inorganic compounds, and prepared tables of the best values of the constants pertaining to many reactions of inorganic chemistry. Most of the data used in this paper are from this source. Volume VII of the International Critical Tables (8) contains most of the data on free energies and equilibrium constants and their change with temperature. Since the data have not been revised recently, later literature should be examined for better values of these quantities. The Debye-Hückel theory of electrolytes is more completely discussed by F. H. MacDougall (2) and by D. A. MacInnes (3).

Conclusion:

It is hoped that the paper will stimulate interest in a subject that is highly developed theoretically, but is too seldom applied to practical problems. Such application will bring out the fact that the existing data, especially as regards changes of electrolytic equilibria with temperature, are fragmentary. Appreciation of this state of affairs should encourage research in the measurement of the various fundamental constants pertaining to the many reactions of industrial interest.

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(11) W. M. Latimer, K. S. Pitzer, and W. V. Smith, "The Entropies of Aqueous Ions," *Journal*, Am. Chemical Soc., Vol. 60, p. 1829 (1938).

[For Discussion, see page 1218.—Ed.]

THE CALCULATION OF THE DISTRIBUTION OF CARBON DIOXIDE BETWEEN WATER AND STEAM

By A. M. Amorosi[1] and J. R. McDermet[1]

Synopsis

This paper first discusses very briefly the significance of dissolved carbon dioxide in water and then proceeds with similar brevity to discuss the underlying principles of apparatus for removing dissolved gases from water by mechanical methods as opposed to chemical fixation methods. Processes of the mechanical type are known to be the use of different methods of attempting to bring water into equilibrium with a degassifying atmosphere which is controlled for proper functioning. In the course of this discussion, the behavior of CO_2, which combines chemically with water and is ionized in solution, is differentiated from the behavior of permanent gases such as oxygen. The fundamental factors which control ionization, such as temperature, pH of solution, and the interrelation between pH and temperature, are discussed.

The general facts summarized in the preceding paragraph are applied in detail by calculating the distribution of CO_2 in water among its several forms—H_2CO_3, HCO_3^- and $CO_3^=$. These calculations and the method for obtaining them, which is presented in detail, take account of the changes in ionization forms, the variations of solubility with temperature, and the change of pH with temperature. The method is presented for calculating these values at any temperature, and detailed calculations are presented for a series of temperatures characteristic of industrial hot water supply.

The extent of the application of these data is shown in the concluding section by applying it to a deaerating feedwater heater of conventional form and known performance, when operating upon dissolved oxygen.

Commercial deaeration apparatus for the removal of permanent gases, notably oxygen, from industrial water supplies is available, which accomplishes the removal to a residual below the limits of chemical or physical determination. Completeness of removal of dissolved oxygen may be further insured beyond this uncertainty by the addition of clean-up or fixation reagents such as sodium sulfite so that oxygen has ceased to be a significant factor in causing internal corrosion of water-carrying pipes and vessels within the pH limits in which oxygen is the controlling factor. Accordingly, attention is now being directed to the control of carbon dioxide concentration, both free and combined, as the next feasible step toward further progress in controlling such forms of corrosion.

Mechanical deaeration equipment depends for its successful operation upon an intelligent utilization of (1) Henry's law, (2) temperature-solubility relationships for CO_2 in water, and (3) the law of mass action.

Henry's law, stated in its simplest

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[1] Engineer, and Chief Engineer, respectively, Elliott Co., Jeannette, Pa.

non-mathematical form, is that any gas which does not combine chemically with a given liquid is soluble in the liquid in direct proportion to the partial pressure of the gas in the region from which solution was attained. It is significant in this statement that the solubility varies with the partial pressure of the gas in question and is independent of other gases which may be present in the region from which solubility was secured. Conversely, it is also true, according to this statement, that a means of reducing gas in solution is to agitate the liquid in a region in which the pressure of the significant gas is controlled to a very low value. The word "controlled" implies the continuous maintenance of desired pressure relationships, which in practice can be attained only by continuously changing the degasifying atmosphere since, in the process of gas removal, the pressure relationships are continuously being depreciated by contamination from the gas given off by the liquid.

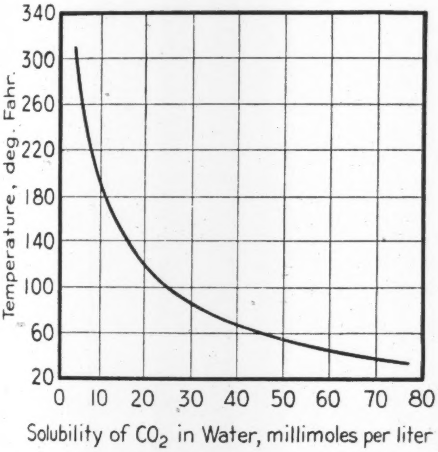

FIG. 1.—Solubility of Carbon Dioxide in Water with One Atmosphere of CO_2 Pressure.

The solubility of CO_2 in water varies inversely as the temperature. This relationship is given in Fig. 1 for a partial pressure of one atmosphere. The benefits from reduced solubility at elevated temperatures along with reduced partial pressures by the control of steam atmospheres can be combined in gas removal at high temperatures. In the control, large quantities of a diluent gas or vapor are necessary. Steam is an advantageous medium, involving no preliminary scrubbing to remove traces of the significant gas.

Henry's law and temperature-solubility relationships for CO_2 in water do not take into consideration the factor of time for attaining equilibrium. This is cared for in practical apparatus by some form of agitation for the purpose of bringing the liquid and the degasifying atmosphere into more intimate contact. Rate of removal is further accelerated by reducing the significant gas content in the degasifying atmosphere to the lowest attainable value in order to facilitate speed of removal. It is also affected by the viscosity of the water itself. A water of low viscosity allows a greater transfer of free CO_2 in the liquid. Since viscosity is a function of temperature, a high degasifying temperature again is indicated. Size considerations of the apparatus involved rarely if ever permit complete equilibrium to be attained.

Carbon dioxide dissolved in water exists in three forms in equilibrium with each other: H_2CO_3 (gaseous CO_2), bicarbonate ion, and carbonate ion. According to the law of mass action, the velocity or rate of chemical reaction is proportional to the active masses of the reacting substances present at any time; at equilibrium this can be restated: the product of the equilibrium concentrations of the product, divided by that of the reactants, is a constant. By the application of this law, the exact proportion of each of the forms of CO_2 can be accurately determined.

That portion of dissolved carbon dioxide existing in the gaseous form is subject to removal as Henry's law and solubility-temperature relationships direct. Those portions existing in ionized form as bicarbonate and carbonate ions are not in themselves subject to removal. However, the displacement of the equilibrium resulting from the removal of the gaseous form involves a change in form from carbonate and bicarbonate ions into the gaseous form and to the extent that this change in form occurs in the actual processing of the liquid, these two forms are likewise amenable to the workings of the removal process. Of the several factors which regulate the rapidity of this shifting phase, four at least are involved in the processing: time; temperature as related to the speed of chemical reaction and speed of transfer through the liquid due to such things as viscosity; driving force, or amount of off-balance away from equilibrium conditions (this is naturally a function of the rate of removal of the gas form); and concentration of the substances involved. The pH of the water, due to greater ionization at higher temperatures, is reduced and the consequent redistribution throws more CO_2 into the gas form.

To compare removal of CO_2 with the removal of permanent gases such as oxygen, two facts must be considered: the solubility of CO_2 in water is many times greater than that of oxygen; oxygen does not ionize whereas CO_2 does. If comparable results are to be obtained, it is necessary to use lower concentrations of CO_2 in the degasifying atmosphere than would be the case with oxygen, better dispersion of the water in contact with the atmosphere, and longer time of treatment, this latter having added significance due to the time required for change in form of carbon dioxide from carbonate and bicarbonate ions to dissolved gas.

This paper therefore presents methods of calculation and calculations resulting from the application of these methods to a series of temperatures, and furnishes data on the resulting change in distribution between the forms in solution. Temperatures have been selected characteristic of boiler water processing with which the authors have the most interest and knowledge.

One set of calculations is supplied for a usual temperature of 77 F. (25 C.) as of utility in chemical testing. Methods of proceeding from the data of one temperature to the data of another temperature are indicated. A method not original with but preferred by the authors for the determination of CO_2 is outlined briefly with reference to its origin. It appears impractical with the present state of knowledge and apparatus actually to test samples at elevated temperature of operation.

No attempt so far has been made by the authors to investigate the theoretical rate of change between the three forms of CO_2 in solution when the equilibrium is displaced by removal of the gas form. Such study as has been given preliminarily indicates quite a complicated relationship which it will be difficult to reduce to practical usage. Test results made upon cooled samples subsequent to the treatment involve three factors. One of these has been mentioned, the time involved in the actual mechanical handling of the liquid in degasifying it as controlling the amount of exposure and the extent of the removal from instant to instant. Other factors of significance are the time of storage in the apparatus between the sampling and the end of the treatment, which terminates when the water particles come into the storage space, and the manipulation of sampling, which is in itself time consuming. Obviously, while the extent of total removal can be determined analytically and at leisure, it does not present a true picture of the form changes which CO_2 undergoes.

In order to provide some background of practical judgment, CO_2 removal tests were made upon a deaerating heater of the spray type which was selected arbitrarily as a cheap and convenient device for testing, and which had a known oxygen removal performance upon normal water supplies resulting in a residual between 0.008 and 0.010 p.p.m. of O_2. Water after treatment was removed as promptly as it could be collected, cooled to a temperature of approximately 77 F. and analyzed by a rapid method which is briefly outlined in the following sections of this paper, the method being selected fundamentally for its speed of manipulation. Values of pH which are significant were taken by a continuous flow glass electrode after cooling. Other data accumulated but not included in this paper on account of space limitations indicate better results upon other types of mechanical degasifying equipment where the actual time of the treatment was extended by mechanical filming over wetted surface. Data are presented for two different pH levels upon a water supply from the same source, differing only by the acid treatment necessary to lower the pH.

TABLE I.

T	$\frac{[H_2CO_3]}{[\text{Total } CO_2]} = \frac{1}{1+\frac{K_1}{[H^+]}+\frac{K_1 \cdot K_2}{[H^+]^2}}$	$\frac{[HC\bar{O}_3]}{[\text{Total } CO_2]} = \frac{\frac{K_1}{[H^+]}}{1+\frac{K_1}{[H^+]}+\frac{K_1 \cdot K_2}{[H^+]^2}}$	$\frac{[C\bar{\bar{O}}_3]}{[\text{Total } CO_2]} = \frac{\frac{K_1 \cdot K_2}{[H^+]^2}}{1+\frac{K_1}{[H^+]}+\frac{K_1 \cdot K_2}{[H^+]^2}}$
77 F. (25 C.) $K_1 = 10^{-6.4559}$ $K_2 = 10^{-10.4145}$	$\frac{1}{1+10^{(x-6.456)}+10^{(2x-16.870)}}$	$\frac{10^{(x-6.456)}}{1+10^{(x-6.456)}+10^{(2x-16.870)}}$	$\frac{10^{(2x-16.870)}}{1+10^{(x-6.456)}+10^{(2x-16.870)}}$
150 F. (65.56 C.) $K_1 = 10^{-6.2043}$ $K_2 = 10^{-10.0979}$	$\frac{1}{1+10^{(x-6.204)}+10^{(2x-16.302)}}$	$\frac{10^{(x-6.204)}}{1+10^{(x-6.204)}+10^{(2x-16.302)}}$	$\frac{10^{(2x-16.302)}}{1+10^{(x-6.204)}+10^{(2x-16.302)}}$
215 F. (101.67 C.) $K_1 = 10^{-5.978}$ $K_2 = 10^{-9.8735}$	$\frac{1}{1+10^{(x-6.026)}+10^{(2x-15.900)}}$	$\frac{10^{(x-6.026)}}{1+10^{(x-6.026)}+10^{(2x-15.900)}}$	$\frac{10^{(2x-15.900)}}{1+10^{(x-6.026)}+10^{(2x-15.900)}}$
235 F. (112.78 C.) $K_1 = 10^{-5.978}$ $K_2 = 10^{-9.8131}$	$\frac{1}{1+10^{(x-5.978)}+10^{(2x-15.791)}}$	$\frac{10^{(x-5.978)}}{1+10^{(x-5.979)}+10^{(2x-15.791)}}$	$\frac{10^{(2x-15.791)}}{1+10^{(x-5.978)}+10^{(2x-15.791)}}$
255 F. (123.89 C.) $K_1 = 10^{-5.9281}$ $K_2 = 10^{-9.7503}$	$\frac{1}{1+10^{(x-5.928)}+10^{(2x-15.678)}}$	$\frac{10^{(x-5.928)}}{1+10^{(x-5.928)}+10^{(2x-15.678)}}$	$\frac{10^{(2x-15.678)}}{1+10^{(x-5.928)}+10^{(2x-15.678)}}$
275 F. (135 C.) $K_1 = 10^{-5.8894}$ $K_2 = 10^{-9.7018}$	$\frac{1}{1+10^{(x-5.889)}+10^{(2x-15.591)}}$	$\frac{10^{(x-5.889)}}{1+10^{(x-5.889)}+10^{(2x-15.591)}}$	$\frac{10^{(2x-15.591)}}{1+10^{(x-5.889)}+10^{(2x-15.591)}}$
295 F. (146 11 C.) $K_1 = 10^{-5.8489}$ $K_2 = 10^{-9.6505}$	$\frac{1}{1+10^{(x-5.849)}+10^{(2x-15.499)}}$	$\frac{10^{(x-5.849)}}{1+10^{(x-5.849)}+10^{(2x-15.499)}}$	$\frac{10^{(2x-15.499)}}{1+10^{(x-5.849)}+10^{(2x-15.499)}}$
315 F. (157.22 C.) $K_1 = 10^{-5.8102}$ $K_2 = 10^{-9.6019}$	$\frac{1}{1+10^{(x-5.810)}+10^{(2x-15.412)}}$	$\frac{10^{(x-5.810)}}{1+10^{(x-5.810)}+10^{(2x-15.412)}}$	$\frac{10^{(2x-15.412)}}{1+10^{(x-5.810)}+10^{(2x-15.412)}}$

The first part of this paper will be devoted to the derivation of applicable formulas, charts and tables. The second part will be devoted to a method of testing for CO_2 and its distribution. The last part will be devoted to a discussion of the limitations and extent of its removal. The calculations presented will be limited to a temperature range between 77 and 315 F., as representing the present-day range of operation of permanent gas removing equipment. Formulas are included which can be used to obtain data at other temperatures.

TABLE II.

(Data from International Critical Tables)		(Data Interpolated from Columns to the left)	
Temperature, deg. Cent.	Y (where $K_w = 10^{-y}$)	Temperature	Y (where $K_w = 10^{-y}$)
0	14.93	77 F. (25 C.)	14
5	14.72		
10	14.53	150 F. (65.56 C.)	12.91
15	14.34		
20	14.16	215 F. (101.67 C.)	12.265
25	14.00		
30	13.83	235 F. (112.78 C.)	12.10
35	13.67		
40	13.52	255 F. (123.89 C.)	11.94
45	13.39		
50	13.26	275 F. (135.0 C.)	11.785
60	13.03		
70	12.82	295 F. (146.11 C.)	11.66
80	12.63		
90	12.45	315 F. (157.22 C.)	11.565
100	12.29		
150	11.63		
200	11.26		
250	11.17		
300	11.40		
306	11.46		

DERIVATION OF FORMULAS AND CHARTS

The following factors are useful for interpreting the data herein presented:

ml. per liter × 0.045 = millimoles per liter

millimoles per liter × 44 = p.p.m. of CO_2

ml. per liter × 1.98 = p.p.m. of CO_2

ml. per liter × 1.43 = p.p.m. of O_2

As would be expected, both primary and secondary dissociation constants for dissolved carbon dioxide vary with temperature. Similarly, the dissociation constants for water vary with temperature.

The dissociation constants for CO_2 have been determined at room temperature by other investigators and these constants have been calculated by the authors at elevated temperatures by use of the van't Hoff equation as follows:

$$\frac{d \log_e K}{dT} = \frac{\Delta H}{RT^2}$$

$$\log_{10} K_b = \log_{10} K_a + \frac{H}{4.578}\left(\frac{1}{T_a} - \frac{1}{T_b}\right)$$

$$K_{a1} = 3.5 \times 10^{-7} \text{ or } 10^{-6.4559} \text{ at } 25 \text{ C. and } H_1 = 2868$$

$$K_{a2} = 3.85 \times 10^{-11} \text{ or } 10^{-10.4145} \text{ at } 25 \text{ C. and } H_2 = 3609$$

At any temperature T (deg. Kelvin)

$$\log_{10} K_{b1} = \log_{10} 10^{-6.4559} + \frac{2868}{4.578}\left(\frac{1}{298} - \frac{1}{T}\right)$$

$$\log_{10} K_{b2} = \log_{10} 10^{-10.4145} + \frac{3609}{4.578}\left(\frac{1}{298} - \frac{1}{T}\right)$$

The dissociation constants K_1 and K_2 calculated in this manner are given in the left-hand column of Table I for the temperatures to be considered in this paper. (The numerical values of K_1 and K_2 will be subject to revision as further research data are accumulated.)

The distribution of CO_2 in its three forms, H_2CO_3 (free CO_2), HCO_3^-, and $CO_3^=$, is determined by the law of mass action and is completely covered in a paper by McKinney.[2] Briefly:

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

$$K_1 = \frac{(H^+)(HCO_3^-)}{H_2CO_3}$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^=$$

$$K_2 = \frac{(H^+)(CO_3^=)}{HCO_3^-}$$

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[2] D. S. McKinney, "Interpretation of Water Analysis," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 3, No. 2, p. 192 (1931).

D. S. McKinney, "The Calculation of Equilibria in Dilute Water Solutions," 1191.

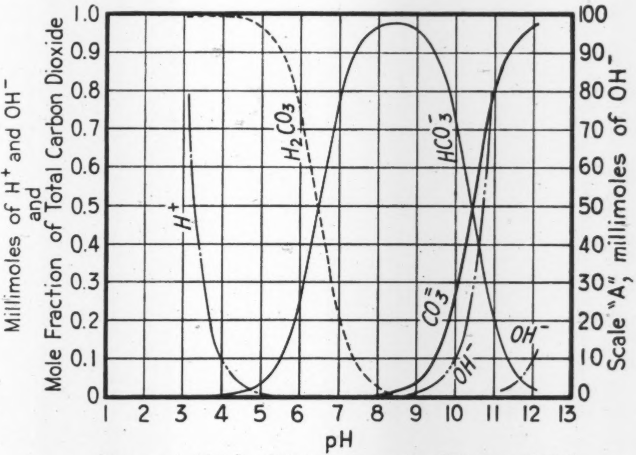
The CO_2 distribution in its various forms is dependent on the distribution constants K_1 and K_2 (which in turn are dependent on temperature) and on the pH value of the water and, as derived from the above equations, is expressed by the equations given at the top of Table I. Table I gives the formulas from which the distribution of CO_2 has been calculated. In this table, X is the pH value or $10^{-X} = H^+$ (hydrogen ion concentration in moles). Table III gives the calculated results. This table, as will be shown later, is useful in finding the distribution of CO_2 at the operating temperature. Without it, considerable work would be involved in finding this distribution.

The dissociation constants for water at elevated temperatures as obtained from the International Critical Tables are given in Table II and the values of the dissociation constants used for illustrative purposes have been interpolated from this data. Again, by the law of mass action:

$$H_2O \rightleftharpoons H^+ + OH^- \text{ and } K_w = (H^+)(OH^-)$$

the OH^- and H^+ concentrations can be found for any pH and temperature and are given in Table III.

Thus Table III gives the mole fractions of the CO_2 and the OH^- and H^+ concentrations for the listed temperatures and pH's. These data can be better expressed in a curve form but due to the mechanics of publication, this cannot be done with the accuracy required. However, for illustrative purposes, Fig. 2 is included to show the form of these curves. An example showing the use of the tabulated data will be given later.



(Use scale "A" for OH^- between pH of 11.2 and 12.1)

FIG. 2.—Relation of pH with CO_2 Distribution and H_2O Ionization at 77 F. Temperature.

Figure 1 shows the solubility of CO_2 in water. The data for this curve were taken from the International Critical Tables.

It should be noted that all calculations herein presented are based on the molal concentrations being equal to the activity of the substance. Although this is not strictly true, the error involved is negligible.[2]

The distribution shown in Table III should be and is believed by the authors to be correct, independent of the pres-

TABLE III.—MOLE FRACTION OF CO_2 IN ITS VARIOUS FORMS AND H^+ AND H^- CONCENTRATIONS.

pH	$H^+ \times 10^3$	H_2CO_3	HCO_3^-	$CO_3^=$	$\overline{OH} \times 10^3$	H_2CO_3	HCO_3^-	$CO_3^=$	$\overline{OH} \times 10$
			77 F. (25 C.)				150 F. (65.56 C.)		
3.1	0.7944	0.9996	0.0004			0.9992	0.0008		
3.4	0.3980	0.9991	0.0009			0.9985	0.0015		
3.7	0.1995	0.9982	0.0018			0.9969	0.0031		
4.0	0.1000	0.9965	0.0035			0.9938	0.0062		
4.3	0.0512	0.9931	0.0069			0.9877	0.0123		
4.6	0.0251	0.9863	0.0137			0.9757	0.0243		
4.9	0.0123	0.9730	0.0270			0.9527	0.0473		
5.2	0.0063	0.9474	0.0526			0.9098	0.0902		
5.5	0.0032	0.9003	0.0997			0.8350	0.1650		
5.8	0.0016	0.8191	0.1809			0.7173	0.2827		0.0001
6.1	0.0008	0.6942	0.3058			0.5598	0.4402		0.0002
6.4	0.0004	0.5321	0.4678	0.0001		0.3837	0.6162	0.0001	0.0003
6.7	0.0002	0.3631	0.6368	0.0001	0.0001	0.2420	0.7577	0.0003	0.0006
7.0	0.0001	0.2222	0.7775	0.0003	0.0001	0.1379	0.8614	0.0007	0.0012
7.3	0.0001	0.1252	0.8741	0.0007	0.0002	0.0741	0.9244	0.0015	0.0025
7.6		0.0669	0.9317	0.0014	0.0004	0.0384	0.9586	0.0030	0.0049
7.9		0.0346	0.9625	0.0029	0.0008	0.0196	0.9742	0.0062	0.0097
8.2		0.0176	0.9764	0.0060	0.0016	0.0098	0.9779	0.0123	0.0195
8.5		0.00884	0.9792	0.0120	0.0032	0.0049	0.9706	0.0245	0.0389
8.8		0.00440	0.9720	0.0236	0.0063	0.0024	0.9498	0.0478	0.0768
9.1		0.00216	0.9517	0.0461	0.0123	0.0011	0.9077	0.0912	0.1550
9.4		0.00103	0.9099	0.0891	0.0251	0.00052	0.8358	0.1637	0.3060
9.7		0.000478	0.8378	0.1617	0.0502	0.00023	0.7141	0.2857	0.6160
10.0		0.000206	0.7218	0.2780	0.1000	0.000089	0.5561	0.4439	1.2190
10.3		0.0000809	0.5655	0.4344	0.1995	0.000031	0.3858	0.6142	2.4450
10.6		0.0000283	0.3947	0.6053	0.3981	0.0000096	0.2393	0.7607	4.9000
10.9		0.00000886	0.2464	0.7536	0.7944	0.0000027	0.1362	0.8638	7.9400
11.2		0.00000254	0.1408	0.8592	1.5850	0.00000074	0.0732	0.9268	19.5000
11.5		0.00000069	0.0759	0.9241	3.1620	0.00000019	0.0381	0.9619	38.9000
11.8		0.00000018	0.0395	0.9605	6.3100	0.00000005	0.0195	0.9805	76.8000
12.1		0.00000005	0.0202	0.9798	12.6000	0.00000001	0.0098	0.9902	155.0000
			215 F. (101. 67 C.)				235 F. (112.78 C.)		
3.1	0.7944	0.9988	0.0012			0.9987	0.0013		
3.4	0.3980	0.9976	0.0024			0.9974	0.0026		
3.7	0.1995	0.9953	0.0047			0.9948	0.0052		
4.0	0.1000	0.9907	0.0093			0.9899	0.0101		
4.3	0.0512	0.9816	0.0184			0.9795	0.0205		
4.6	0.0251	0.9639	0.0361			0.9598	0.0402		
4.9	0.0123	0.9304	0.0696			0.9229	0.0771		0.0001
5.2	0.0063	0.8701	0.1299		0.0001	0.8571	0.1429		0.0001
5.5	0.0032	0.7704	0.2296		0.0002	0.7504	0.2496		0.0003
5.8	0.0016	0.6272	0.3728		0.0003	0.6010	0.3990		0.0005
6.1	0.0008	0.4574	0.5425	0.0001	0.0007	0.4302	0.5697	0.0001	0.0010
6.4	0.0004	0.2970	0.7028	0.0002	0.0014	0.2745	0.7252	0.0003	0.0020
6.7	0.0002	0.1746	0.8248	0.0006	0.0027	0.1592	0.8402	0.0006	0.0040
7.0	0.0001	0.0959	0.9029	0.0012	0.0054	0.0867	0.9119	0.0014	0.0079
7.3	0.0001	0.0504	0.9471	0.0025	0.0108	0.0453	0.9518	0.0029	0.0158
7.6		0.0258	0.9690	0.0052	0.0216	0.0232	0.9709	0.0059	0.0316
7.9		0.0131	0.9765	0.0104	0.0432	0.0116	0.9765	0.0119	0.0631
8.2		0.00651	0.9729	0.0206	0.0860	0.00582	0.9706	0.0236	0.1260
8.5		0.00321	0.9564	0.0404	0.1719	0.00285	0.9509	0.0463	0.2510
8.8		0.00154	0.9206	0.0779	0.3430	0.00137	0.9094	0.0893	0.0502
9.1		0.000721	0.8553	0.1440	0.6840	0.000632	0.8373	0.1621	1.0000
9.4		0.000316	0.7481	0.2516	1.3650	0.000273	0.7213	0.2785	1.9930
9.7		0.000126	0.5984	0.4015	2.7250	0.000107	0.5646	0.4353	3.9800
10.0		0.0000454	0.4278	0.5721	5.4400	0.0000384	0.3871	0.6129	7.9440
10.3		0.0000144	0.2726	0.7274	10.8400	0.0000117	0.2458	0.7542	15.8300
10.6		0.00000421	0.1581	0.8419	21.6500	0.00000335	0.1404	0.8596	31.6000
10.9		0.00000114	0.0862	0.9138	43.2000	0.00000090	0.0756	0.9244	63.1000
11.2		0.00000030	0.0450	0.9550	86.0000	0.00000024	0.0394	0.9606	126.0000
11.5		0.00000008	0.0231	0.9769	171.9000	0.00000006	0.0201	0.9799	251.0000
11.8		0.00000002	0.0106	0.9894	343.0000	0.00000002	0.0101	0.9899	502.0000
12.1		0.00000001	0.0056	0.9944	684.0000	0.00000000	0.0051	0.9949	1000.0000

TABLE III.—*Continued.*

pH	$H^+ \times 10^3$	H_2CO_3	HCO_3^-	$CO_3^=$	$\overline{OH} \times 10^3$	H_2CO_3	HCO_3^-	$CO_3^=$	$\overline{OH} \times 10^3$
		255 F. (123.89 C.)				275 F. (135.0 C.)			
3.1	0.7944	0.9985	0.0015			0.9984	0.0016		
3.4	0.3980	0.9971	0.0029			0.9968	0.0032		
3.7	0.1995	0.9941	0.0059			0.9936	0.0064		
4.0	0.1000	0.9883	0.0117			0.9873	0.0127		
4.3	0.0512	0.9770	0.0230			0.9749	0.0251		
4.6	0.0251	0.9552	0.0448			0.9512	0.0488		0.0001
4.9	0.0123	0.9143	0.0857		0.0001	0.9073	0.0927		0.0001
5.2	0.0063	0.8408	0.1592		0.0002	0.8309	0.1691		0.0003
5.5	0.0032	0.7282	0.2718		0.0004	0.7103	0.2897		0.0005
5.8	0.0016	0.5726	0.4274		0.0007	0.5513	0.4487	0.0001	0.0010
6.1	0.0008	0.4022	0.5977	0.0001	0.0014	0.3811	0.6188	0.0001	0.0021
6.4	0.0004	0.2522	0.7475	0.0003	0.0029	0.2357	0.7639	0.0004	0.0041
6.7	0.0002	0.1446	0.8546	0.0008	0.0058	0.1337	0.8654	0.0009	0.0082
7.0	0.0001	0.0780	0.9204	0.0016	0.0115	0.0718	0.9264	0.0018	0.0164
7.3	0.0001	0.0406	0.9560	0.0034	0.0229	0.0372	0.9590	0.0038	0.0328
7.6		0.0207	0.9726	0.0067	0.0457	0.0189	0.9734	0.0077	0.0654
7.9		0.0104	0.9760	0.0136	0.0912	0.00951	0.9751	0.0154	0.1303
8.2		0.00517	0.9676	0.0273	0.1820	0.00472	0.9649	0.0304	0.2600
8.5		0.00253	0.9439	0.0536	0.3633	0.00230	0.9387	0.0590	0.5190
8.8		0.00120	0.8984	0.1004	0.7245	0.00109	0.8878	0.1112	1.0360
9.1		0.000568	0.8163	0.1832	1.4450	0.000492	0.7990	0.2006	2.0650
9.4		0.000233	0.6939	0.3059	2.8850	0.000211	0.6670	0.3328	4.1200
9.7		0.0000894	0.5289	0.4711	5.7650	0.0000775	0.5010	0.4990	8.2250
10.0		0.0000305	0.3601	0.6399	11.4900	0.0000259	0.3348	0.6652	16.4000
10.3		0.0000093	0.2204	0.7796	22.9200	0.00000783	0.2015	0.7985	32.7500
10.6		0.00000263	0.1235	0.8765	45.7000	0.00000219	0.1123	0.8877	65.4000
10.9		0.00000071	0.0662	0.9338	91.2000	0.00000058	0.0596	0.9404	130.3000
11.2		0.00000018	0.0343	0.9657	182.0000	0.00000015	0.0308	0.9692	260.0000
11.5		0.00000005	0.0175	0.9825	363.3000	0.00000004	0.0157	0.9843	519.0000
11.8		0.00000001	0.0088	0.9912	724.5000	0.00000001	0.0079	0.9921	1036.0000
12.1		0.00000000	0.0044	0.9956	1445.0000	0.00000000	0.0040	0.9960	2065.0000
		295 F. (146.11 C.)				315 F. (157.22 C.)			
3.1	0.7944	0.9982	0.0018			0.9981	0.0019		
3.4	0.3980	0.9965	0.0035			0.9962	0.0038		
3.7	0.1995	0.9930	0.0070			0.9923	0.0077		
4.0	0.1000	0.9859	0.0141			0.9848	0.0152		
4.3	0.0512	0.9725	0.0275			0.9701	0.0299		0.0001
4.6	0.0251	0.9466	0.0534		0.0001	0.9420	0.0580		0.0001
4.9	0.0123	0.8981	0.1019		0.0002	0.8905	0.1095		0.0002
5.2	0.0063	0.8167	0.1833		0.0003	0.8030	0.1970		0.0004
5.5	0.0032	0.6906	0.3094	0.0002	0.0007	0.6713	0.3287		0.0009
5.8	0.0016	0.5279	0.4720	0.0006	0.0014	0.5058	0.4942		0.0017
6.1	0.0008	0.3593	0.6406	0.0001	0.0028	0.3390	0.6608	0.0002	0.0034
6.4	0.0004	0.2194	0.7802	0.0004	0.0055	0.2045	0.7951	0.0004	0.0068
6.7	0.0002	0.1234	0.8756	0.0010	0.0110	0.1140	0.8849	0.0011	0.0137
7.0	0.0001	0.0654	0.9325	0.0021	0.0219	0.0605	0.9372	0.0023	0.0273
7.3	0.0001	0.0340	0.9617	0.0043	0.0436	0.0312	0.9640	0.0048	0.0544
7.6	0.0000	0.0173	0.9741	0.0086	0.0871	0.0158	0.9745	0.0097	0.1084
7.9		0.00864	0.9742	0.0172	0.1738	0.00791	0.9728	0.0193	0.2165
8.2		0.00424	0.9617	0.0341	0.3467	0.00391	0.9583	0.0378	0.4320
8.5		0.00210	0.9318	0.0661	0.6915	0.00189	0.9250	0.0732	0.8600
8.8		0.000979	0.8755	0.1236	1.3800	0.000883	0.8629	0.1362	1.7190
9.1		0.000437	0.7800	0.2196	2.7550	0.000390	0.7602	0.2394	3.4300
9.4		0.000197	0.6391	0.3608	5.5000	0.000158	0.6141	0.3858	6.8400
9.7		0.0000664	0.4713	0.5287	10.9600	0.0000573	0.4444	0.5556	13.6500
10.0		0.0000217	0.3098	0.6902	21.8600	0.0000184	0.2856	0.7144	27.2500
10.3		0.00000647	0.1831	0.8169	43.6000	0.00000541	0.1670	0.8330	54.4000
10.6		0.00000179	0.1010	0.8990	87.0500	0.00000148	0.0913	0.9087	108.4000
10.9		0.00000047	0.0535	0.9465	173.8000	0.00000039	0.0479	0.9521	216.5000
11.2		0.00000012	0.0274	0.9726	346.7000	0.00000010	0.0247	0.9753	432.0000
11.5		0.00000003	0.0139	0.9861	691.5000	0.00000003	0.0125	0.9875	860.0000
11.8		0.00000001	0.0070	0.9930	1380.0000	0.00000001	0.0063	0.9937	1718.0000
12.1		0.00000000	0.0035	0.9965	2753.0000	0.00000000	0.0031	0.9969	3425.0000

ence of other ions. The test method outlined later is not applicable in the presence of other weakly ionized compounds. Such an ion is obviously phosphate in its primary and secondary ionization forms. A similar table can be derived covering phosphate radical and carbon dioxide in combination, but increases the complication of the method and requires an accurate determination of phosphate. Accordingly, no attempt is made in this paper to include the phosphate ion. Since phosphate is present almost universally as a water conditioning compound, deliberately added, it is recommended that phosphate additions be temporarily discontinued during the period of carbonate determination. It should be emphasized that if this is not done, results determined by the use of Table III will be in error.

METHODS OF DETERMINING CO_2 AND ITS DISTRIBUTION AT THE OPERATING TEMPERATURE

The following steps should be taken to determine dissolved CO_2 and its distribution at the operating temperature:

1. Obtain pH of both ingoing and effluent water at room temperature (70 to 85 F). Although the pH is actually desired at the operating temperature, no method is now available to find it at this temperature, so the pH must be obtained at room temperature and then by use of Table III, must be converted.

2. Find the total CO_2 in the water.

The following method is preferred by the authors because of its greater rapidity. Total CO_2 determined by the evolution method is, however, more accurate at the expense of lower speed.

(*a*) Titrate to find the millimoles of H^+ equivalent required to reduce 1 liter of the water from pH 8.5 (thymol blue) to 5.0 (brom-cresol green), using NaOH or H_2SO_4 accordingly as the pH found is below or above the indicator point.

(*b*) Find the total CO_2 in the water by use of the formula:

$$\text{Total millimoles } CO_2 = \frac{H^+ - 0.0132}{0.974}$$

This formula merely expresses the law of electrical neutrality—the fact that the shift in ionization of water when changing from a pH of 8.5 to 5.0 at 77 F. must be taken up by the CO_2 ions.

3. (*a*) Look up the distribution of the CO_2 in its various forms on the 77 F distribution curve, and

(*b*) Calculate the weak ion concentration at this temperature.

4. Find the distribution of CO_2 in its various forms at the operating temperature.

By the law of electrical neutrality, the total ion charges should equal zero. Since the strong acids, bases, and salts do not change their ionization with temperature (within the range considered), the total ion concentration of weak acids, bases, and salts must always equal the same amount. Thus, the total ionization of these weakly ionized substances (in the case here considered this means H_2CO_3 and H_2O) must equal a constant.

Find the distribution of the CO_2 at the operating temperature which will give the same weak ion concentration as that found at 77 F. This last step must be found by successive approximations. An accuracy of 0.1 pH is consistent.

Example

Samples were taken of the water both entering and leaving a deaerator operating at a temperature of 215 F. and the following data were collected:

	Water Entering Deaerator	Water Leaving Deaerator
Total Quantity	65,000 lb. per hr.	74,000 lb. per hr.
pH at approx. 77 F.	7.35	9.1
Amount of titration required to titrate 100 ml. of sample to:		
Thymol blue (8.5)	0.07 ml. of 0.1044 *N* NaOH	0.4 ml. of 0.02 *N* H_2SO_4
Brom-cresol green (5.0)	2.9 ml. of 0.02 *N* H_2SO_4	2.8 ml. of 0.02 *N* H_2SO_4
Equivalent H^+ ions in millimoles per liter required to change samples from pH 8.5 to 5.0	$0.07 \times 0.1044 \times \frac{1000}{100} = 0.0731$ $2.9 \times 0.02 \times \frac{1000}{100} = \underline{0.58}$ 0.653	2.8 (−) $\underline{0.4}$ 2.4 ml. of 0.02 *N* H_2SO_4 $2.4 \times \frac{1000}{100} \times 0.02 = 0.48$
Total CO_2 in a liter using: Total $CO_2 = \frac{H^+ - 0.0132}{0.974}$	$\frac{0.653 - 0.0132}{0.974} = 0.658$ millimoles per liter	$\frac{0.48 - 0.0132}{0.974} = 0.483$ millimoles per liter

Look up the distribution of the CO_2 and the H^+ and OH^- ions at the temperature at which the pH value was taken, 77 F., and determine the weak ion concentration:

H_2CO_3	0.1135	0.0022
HCO_3^-	$0.8855 \times 1 \times 0.658 = 0.582$	$0.9517 \times 1 \times 0.483 = 0.460$
$CO_3^=$	$0.0010 \times 2 \times 0.658 = 0.0013$	$0.0461 \times 2 \times 0.483 = 0.045$
$OH^- \times 10^3$	$0.0003 \times 1 = 0.0003$	$0.0123 \times 1 = 0.012$
$H^+ \times 10^3$		
Weak ion concentration	(−) $\overline{0.584}$	(−) $\overline{0.517}$

Assume a pH, and using the 215 F. curve determine the CO_2 distribution:

	1st Assumption pH = 6.9	1st Assumption pH = 8.0
H_2CO_3	0.113	0.109
HCO_3^-	$0.887 \times 1 \times 0.658 = 0.583$	$0.9730 \times 1 \times 0.483 = 0.471$
$CO_3^=$	0.000	$0.0161 \times 2 \times 0.483 = 0.016$
$OH^- \times 10^3$	0.006 0.006	$0.0575 \times 1 = 0.058$
$H^+ \times 10^3$		
	(−) $\overline{0.589}$ Close enough	(−) $\overline{0.545}$ Too high, try pH = 7.7
H_2CO_3		0.0216
HCO_3^-		$0.9715 \times 1 \times 0.483 = 0.469$
CO_3		$0.0082 \times 2 \times 0.483 = 0.008$
$OH^- \times 10^3$		$0.0316 \times 1 = 0.032$
$H^+ \times 10^3$		
		(−) $\overline{0.509}$ Close enough

Thus the distribution is:

	Mole Fraction	Millimoles per liter	Mole Fraction	Millimoles per liter
H_2CO_3	0.113×0.658	= 0.075	0.0216×0.483	= 0.010
HCO_3^-	0.887×0.658	= 0.583	0.9715×0.483	= 0.469
$CO_3^=$	0.000		0.0082×0.483	= 0.004

While mathematically rigorous, this procedure is limited by the accuracy attained in selecting constants and by the assumption that the activity coefficient is unity. Its real utility is in obtaining, by calculation, values for which no direct determinations are available. If the distribution is taken from the room temperature chart, it will be in error. The extent of this error can be seen from the above calculations on the water leaving the deaerator. The room temperature chart gives a mole fraction of 0.0022 H_2CO_3, but when readings were corrected for operating temperature, the mole fraction actually was 0.0216, or ten times more.

In routine testing, it may be found that this error is not very significant and that the total CO_2 and its approximate distribution is all that is required. If this is the case, only steps 1 through 3 (*a*) of the above calculations need to be followed.

To simplify step 2 (*b*) above, Fig. 3 is included which can be used to find the total millimoles of CO_2 (a scale is also included showing CO_2 in p.p.m.). This

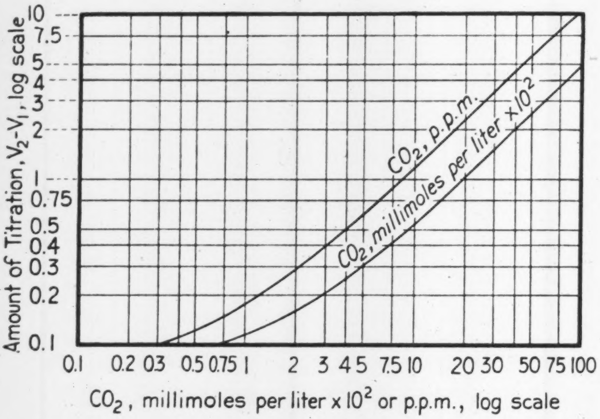


FIG. 3.—Relation of Titration from pH 8.5 to 5.0 to Total CO_2 in p.p.m.

Using 0.02 *N* solution and 100-ml. sample.
v_2 and v_1 equals amount of titration in milliliters required to titrate to 8.5 pH and 5 pH, respectively.

$$CO_2 = \tfrac{44}{50} [(v_2 - v_1)\ 12.36 - 0.813].$$

If pH of sample is above 8.5 use H_2SO_4 for titrating.
If pH of sample is between 8.5 and 5.0 use NaOH for titrating to 8.5 and use $v_1 = (-)$ amount of titration.
If pH of sample is below 5.0 use NaOH for titrating to 8.5 and 5.0 and use v_1 and $v_2 = (-)$ amount of titration.

TABLE IV.—PERFORMANCE OF A DEAERATING HEATER.

	pH as Read, room temperature	pH, operating temperature	Total CO_2		Free CO_2	
			Millimoles per Liter	p.p.m.	Millimoles per Liter	p.p.m.
OPERATING AT 215 F. WITH ALKALINE WATER.						
Water in	7.35	6.9	0.658	29.0	0.074	3.26
"Equivalent water out"		7.8	0.551	24.2	0.007	0.32
Actual water out	9.1	7.8	0.483	21.3	0.007	0.30
Equivalent theoretical at 5 p.p.m. CO_2 in steam	(10.80)	9.0	0.016	0.705	0.000016	0.0007
Equivalent theoretical at 50 p.p.m. CO_2 in steam		8.9	0.125	5.49	0.00016	0.007
OPERATING AT 215 F. WITH ACID WATER.						
Water in	4.67	4.5	0.685	30.1	0.664	29.2
"Equivalent water out"		4.8	0.183	8.05	0.175	7.7
Actual water out	4.93	4.8	0.161	7.08	0.152	6.68
Equivalent theoretical at 50 p.p.m. CO_2 in steam	(4.9)	4.9	0.00017	0.0075	0.00016	0.007

curve is based on using standard 0.02*N* solutions of either H_2SO_4 or NaOH, and on titrating a 100-ml. sample.

Where accuracy of determination is required, it is recommended that a micropipette and an Almquist side-arm flask be used. This flask should have a 100-ml. mark on it.

LIMITATIONS AND EXTENT OF CO_2 REMOVAL

A clear picture of the most favorable operating conditions for CO_2 removal cannot be obtained until (1) the calculations given above are evaluated on a common basis, (2) the theoretical performance of the deaerator is calculated, (3) data on a low pH water for comparison with the data on high pH value given above are obtained.

1. Since the water leaving the deaerator has been diluted by the steam condensed, the CO_2 in this water will show up less concentrated due to this dilution. To obtain the efficiency of removal of CO_2, the effluent readings should be corrected for this. Therefore, the CO_2 in the water leaving should be recalculated and called the "equivalent water leaving." The water leaving showed 0.483 millimoles per liter of CO_2 and a weak ion concentration of (−) 0.517. To correct for dilution, multiply by $\frac{74{,}000}{65{,}000}$, obtaining 0.55 millimoles per liter of equivalent CO_2 concentration and (−) 0.587 equivalent weak ion concentration. (It is assumed that the steam condensed is neutral in ionization and thus dilutes the ionized forms of H_2O and H_2CO_3.)

By successive approximations, the pH at 215 F. is found to be 7.8 and distributed as follows:

	Mole Fraction	Millimoles per liter
H_2CO_3	0.020×0.55	$= 0.011$
HCO_3^-	0.972×0.55	$= 0.535$
$CO_3^=$	0.008×0.55	$= 0.004$

2. The efficiency of removal of CO_2 in a deaerating heater can be evaluated by calculating the theoretical CO_2 which should be left, if the deaerator is such that sufficient time is allowed for an equilibrium to be reached and that the deaerator is truly counter-flow in principle so that the equilibrium is between the incoming steam and the outgoing water.

To calculate the theoretical quantity of CO_2 in the effluent water, the following should be found: (*a*) the partial pressure of the CO_2 in the incoming steam, (*b*) the solubility of CO_2 in water at the operating temperature, (*c*) from (*a*) and (*b*) the free CO_2 (H_2CO_3) in the water, and (*d*) from curves the total CO_2 and its distribution in the water which will give the same total weak ions as the inlet water.

(*a*) By condensing and actually titrating a sample of the steam used, as was done in the second step of the Method of Determining CO_2 and Its Distribution, the CO_2 in the steam was found to be 0.1137 millimoles per liter or 5.0 p.p.m.

or

$$\frac{\frac{5.0}{44}}{\frac{5.0}{44}+\frac{10^6}{18}} = 2.05 \times 10^{-6} \text{ mole fraction}$$

or partial pressure = mole fraction = 2.05×10^{-6} atmospheres.

(*b*) From the solubility curve at 215 F., solubility is 7.7 millimoles per liter.

(*c*) By Henry's law (solubility = partial pressure × solubility factor) $7.7 \times 2.05 \times 10^{-6} = 0.0158 \times 10^{-3}$ millimoles per liter of undissociated CO_2.

(*d*) The inlet water has an excess variable ions of (−) 0.584. By the method of approximations given in the fourth step in the Method of Determining CO_2 and Its Distribution, the pH and distribution of the theoretical outlet water can be found. However, in this case it must be remembered that only the free millimoles of CO_2 are known and not the total. After assuming the pH (and thus distribution of CO_2), we find the total millimoles of

$$CO_2 = \frac{\text{millimoles of } H_2CO_3}{\text{mole fraction } H_2CO_3}$$

Assume pH = 9.00

H_2CO_3		0.0099
HCO_3^-	$0.877 \times 1 \times 0.016^a$	= 0.014
$CO_3^=$	$0.122 \times 2 \times 0.016^a$	= 0.004
$OH^- \times 10^3$	0.571×1	= 0.571
	(−)	0.589

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[a] Before being able to obtain millimoles per liter, the total CO_2 had to be found to be $\frac{0.0158 \times 10^{-3}}{0\ 0099} = 0.016$ millimoles.

This assumption is close enough; in most cases the theoretical water out should have almost all of the variable ions consisting of the OH^- ion for alkaline waters and H^+ for acid waters, so that only one assumption is usually required.

3. Table IV, in addition to the calculations worked out and discussed previously for a deaerator working on relatively high pH, likewise includes the performance of the same deaerator working upon a water of low pH. The low pH was artificially obtained by slug treating with acid the contents of a large wooden storage tank and allowing it to stand for 24 hr. in order that diffusion would take place. The water, before the acid addition, was the same as the water with the high pH. It is realized that this procedure does not give the equivalent of a natural water of low pH content, but it was the only possible procedure for securing comparative results.

Normally, in any such process of CO_2 removal as a deaerating heater employs where the water treated by the unit is used to furnish steam to it for subsequent heating, the results improve continuously, but at a decreasing rate with the time of recycling. In the testing, a deaerator unit of similar capacity to the test unit was operated with treated water at the higher pH content, and its water was used to furnish steam to the test unit, which would be representative of long-time operation. This was done to avoid the necessity of waiting sufficiently long for the equilibrium due to recycling to be obtained, and is thought to be a legitimate approximation.

CONCLUSIONS

The authors, as a result of the material presented in this paper, together with the experience in obtaining it, have reached the following conclusions.

On waters of high pH, excellent removal results can be secured on the gas form of CO_2, since the amount to be removed is sufficiently small so that solubility relationships do not offer a serious limit and the speed of change in form within the solution for the time of processing plus the time of analysis are sufficiently slow so that they do not significantly alter the predicted results. On the other hand, the effluent samples from such a degasifier are sufficiently unstable in form relationship as to raise a serious question of whether the treatment was worth while from the standpoint of CO_2 removal.

On waters of lower pH, significant and valuable removal may be obtained, but solubility and change-in-form relationships intervene to make the actual results less than the expected results. At pH values sufficiently high above the plating temperature of hydrogen to be industrially safe, a long exposure time between liquid and degasifying atmosphere is definitely indicated.

The distribution between solution

forms of CO_2 is so significantly different at elevated temperature, that knowledge of this distribution is necessary both for intelligent understanding of degasifying equipment and the design of it.

Acknowledgments:

The necessity for making this investigation arose unexpectedly so that resources of both time and money were not available to make a detailed empirical investigation. One of the authors was familiar with previous publications by D. S. McKinney, which revealed that it was possible to approach this problem from the standpoint of theory more expeditiously and understandingly than by the laborious, more conventional methods. Mr. McKinney's help was secured and the fundamental bases of this investigation were developed under his direction.

DISCUSSION

Mr. H. H. Uhlig.[1]—I should like to ask Mr. McDermet what basis he has for believing that there is any appreciable time involved in the equilibrium between carbonic acid and carbonate ions?

Mr. A. C. Walker.[2]—These papers are an encouraging indication that sound principles of chemical equilibrium are being discussed and understood by engineers interested in the practical problems associated with the properties of waters used for industrial purposes. Very little practical use has been made of such equilibrium principles in aqueous carbonate solutions until recently, although some of the essential ground work for such use has been available for years.

In discussing the papers by Mr. McKinney, and Messrs. Amorosi and McDermet there are two points which may perhaps deserve special mention.

The van't Hoff equation in the latter paper expressing the effect of temperature upon the carbonate equilibrium

$$\frac{d \log_e K}{dT} = \frac{\Delta H}{RT^2}$$

consists entirely of variable terms except the gas constant R. In arriving at a useful form of this equation for practical purposes, it is assumed that ΔH does not vary within the temperature limits in question. This is not strictly true but may be a reasonable approximation in many cases. The error caused by assuming this ΔH to be constant in the present discussion is much less important than that the significance of this assumption be clearly understood.

The equilibrium in carbonate solutions is an exceedingly complex one, but if certain reasonable simplifying assumptions are made, such as that ΔH is a constant, it is possible to set up tables by means of which the composition and behavior of industrial waters on heating for boiler feed purposes may be computed.

It might be well to point out also that such carbonate equilibria are complicated as well by the presence of salts other than carbonates, such as chlorides, sulfates or nitrates, and the kind and amounts of anions, such as Na, K, Ca, or Mg, are also important. However, it has been shown by Lewis and Randall that when the total ion concentration is low, some function of the total ionic strength of the solution may be used to advantage as a simplifying assumption in certain equilibrium calculations.

To illustrate the general value of the van't Hoff equation it may be of interest to state that, in work done recently by the Drying Research Committee of the United States Institute for Textile Research, use has been made of a similarly formulated equation to express the effect of temperature upon the equilibrium relations between moisture content and atmospheric relative humidity of various textiles such as cotton, silk, and wool. By means of this equation it is possible to calculate the moisture content of a textile over a wide range of equilibrium relative humidities and temperatures within certain useful limits, from experimental data taken at but one or two temperatures within these limits.

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[1] Research Associate, Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

[2] Member of Technical Staff, Bell Telephone Laboratories, Inc., New York City.

THE CHAIRMAN (*Mr. E. P. Partridge*[3]).—That the authors of these two papers have performed a valuable function in giving us some figures at which to shoot goes without saying. We should remember, however, whenever we perform a mathematical operation that the results we take out at the end depend inevitably upon the assumptions we put in at the beginning. When we extrapolate into an unknown region by thermodynamic reasoning and mathematical processes let us then be sure to remember the educated guesses we had to make. This word of caution should in no way detract from the tribute we should pay to Messrs. Amorosi and McDermet for having given us some values in the range of higher temperatures. Perhaps someone will come along 5 yr. from now with direct experimental evidence showing that their predictions were 20 per cent in error. We should not forget then that these authors performed a most valuable function in giving us even reasonably accurate values with which to work, since before their efforts we had nothing at all.

MR. D. S. MCKINNEY.[4]—First, I do not agree with Mr. Amorosi's explanation of the slow rate at which equilibrium is reached. I think the reason for the slow removal of CO_2 is low rates of diffusion rather than the slow rate of attainment of ionic equilibrium. Now, with regard to Mr. Walker's statement regarding the constancy of ΔH in van't Hoff's equation, if we write it in the form $\frac{d \log_e K}{d\left(\frac{1}{T}\right)} = -\frac{\Delta H}{R}$, we see that a plot of the log of the equilibrium constant, against $\frac{1}{T}$, will produce a straight line if ΔH is constant. We did get a straight line for the equilibrium constant of water and for the Henry's law constant for the distribution of CO_2 between the liquid and the gas phases. Hence, this form of the equation would be all right for these cases. With regard to the other equilibria, I do not know. In the absence of any knowledge as to how ΔH varies with temperature, it seems to me that it is better to make the calculations assuming ΔH constant, keeping in mind that the result will be only approximately right, than not to make the calculation at all.

There is one other point I wanted to make. In the calculation Mr. Amorosi made, it was not necessary to take the activity coefficients into account since the waters were sufficiently dilute that they could be assumed to be unity. The error thus introduced is certainly less than the errors in analysis. Only in more concentrated water such as boiler water is it necessary to consider activity coefficients.

MR. PARTRIDGE.—With respect to the maximum in the curve for the variation of the dissociation constant of water with temperature, I believe that similar maxima have been observed in the case of a number of acids. These maxima occurred at various temperatures, all of them, however, considerably below that in the case of water.

MR. J. R. MCDERMET.[5]—The only discussion that needs an explanation is the fact that we attach significance to the rate of change between carbonate and bicarbonate ion and gaseous CO_2 in the three forms of CO_2 which might exist in solution. This is not, from our standpoint, altogether the simple matter of considering the theory of solutions. We have several other things to consider. As nearly as I can explain, I believe that one could safely say that the rate of change between forms would depend on the driving force as occasioned by the removal of one form, but unfortunately in dealing with quantities of water one has several additional problems. The first is the fact that a sudden displacement occurs in the dissolved gaseous form at the interface when treatment is commenced.

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[3] Director of Research, Hall Laboratories, Inc., Pittsburgh, Pa.

[4] Assistant Professor of Chemistry, Carnegie Institute of Technology, Pittsburgh, Pa.

[5] Chief Engineer, Elliott Co., Jeannette, Pa.

In addition to the data we have presented, we have several other investigations where the treatment of water in suspension was delayed by different methods of mechanical filming, but we ourselves do not know precisely the rate from instant to instant at which the gaseous CO_2 was removed. Certainly, it was removed from a boundary layer and diffusion must come into play, and diffusion, in addition, is probably further complicated both by liquid turbulence and viscosity relationships, since viscosity and the resulting turbulence are variable with temperature. We have considered, in addition, that there was one other peculiar variable which is not peculiar when you realize it, that in dealing with water of relatively low pH there was undoubtedly almost an instantaneous adjustment of pH on the boundary surface, but a delay in reproducing the change on the interior layers of the film, which assuredly were not of molecular thickness. The solution form proceeded immediately to change the instant the treatment was attempted.

We had, therefore, quite a complicated phenomenon which we do not think can be systematized without a great deal of detailed investigation. We have not been able to find precisely why one method of filming should differ from another method of filming in effecting behavior of the apparatus. It is sufficient to say that methods of filming which introduce longer times in suspension produce better results. We have found this fact, but we have not, to our own satisfaction, been able to explain it other than to raise this question of shift in form which, to us, was the most reasonable explanation. We will be glad if additional information can be given to us in this respect.

DETERMINATION BY THE EVAPORATION METHOD OF SMALL AMOUNTS OF DISSOLVED SOLIDS IN WATER SUCH AS CONDENSED STEAM FROM BOILERS

By R. C. Ulmer[1]

Synopsis

This investigation was undertaken in an effort to ascertain the applicability of a modified evaporation method for determining the amount of solids present in the steam from boilers. Essentially, the method used consists of evaporating a 5-gal. sample of condensed steam in a weighed platinum dish under conditions which attempt to minimize the possibility of contamination of the sample and residue.

Results obtained by using the suggested apparatus to determine the amount of solids in a sample prepared by adding a known amount of potassium chloride to distilled water of known purity indicate that the method gives accurate and reproducible results. Conductance tests of the same water indicate that the conductance method is satisfactory for determining steam purity when ammonia is absent, provided that the factor relating solids content of the steam to conductance is determined by the evaporation method for each boiler water condition.

Under actual boiler operating conditions in which ammonia was present in the steam, values of steam purity obtained by the conductance and evaporation methods did not agree. The factor relating solids content of the steam to corrected conductance was not constant, indicating that it would be impossible to calibrate readily the conductance method by the evaporation method.

The results obtained in this investigation indicate that accurate determinations of steam purity can be obtained by the evaporation method in from 5 to 7 days. During this period, only a few minutes supervision is required once each day. In case more than 0.5 p.p.m. of solids is present in the steam, a smaller sample may be evaporated, thus proportionately decreasing the time required to obtain results.

The purity of steam from boilers may be estimated by several methods, the procedure chosen in any specific case depending on the accuracy and the nature of the information desired and the conditions under which the test is to be made. Thus, in case the contamination of the steam by boiler water amounts to several per cent, some idea of the amount of carry-over can be obtained by noting the decrease which occurs in the temperature of the superheated steam, a drop of approximately 13 F. taking place for each 1 per cent carry-over for a boiler operating at 400 psi. If the carry-over amounts to 5 per cent or more, the boiler water can be observed visually by scattered light if an intense beam of light is directed along the axis of flow of the steam.

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[1] Chemist, Research Dept., The Detroit Edison Co., Detroit, Mich.

Prior to the last 10 to 20 years, carry-over of the order of 0.5 to 2.0 per cent was determined by means of a steam calorimeter. From this information and a knowledge of the amount of solids in the boiler water, the solids carried over could be determined. This method was quite satisfactory for the determination of carry-over amounting to 1 per cent or more, but since the accuracy of the method is only plus or minus 0.2 per cent of moisture,[2] an error of 4.0 p.p.m. of solids in the steam might be made when applying this method to carry-over of a boiler water containing 2000 p.p.m. of solids. Such a method is not applicable, therefore, to determining small amounts of carry-over.

In the past two decades with the constant trend toward the use of higher steam pressures and higher final steam temperatures, it has become the general intent to limit the carry-over so that something less than one part per million of solids is present in the steam. On a percentage basis for a boiler water containing 200 p.p.m. of solids, carry-over of that order amounts to something less than 0.5 per cent, whereas for a boiler water containing 2000 p.p.m. of solids the percentage is less than 0.05. It is evident, therefore, that the methods so far mentioned are not applicable for the determination of such small amounts of carry-over.

In an effort to meet the need for a method capable of determining such low values, the conductance method was brought into prominence, various modifications being devised from time to time to increase the accuracy of the results. In general, this method, particularly when flow-type cells are used with a degasified condensate, gives reasonably satisfactory results unless ammonia is present. Even in the absence of ammonia, however, there is still considerable doubt regarding the correction for or the completeness of removal of carbon dioxide, the applicability of cell constants at the low electrolyte concentrations involved, and especially the factor used to convert conductance to parts per million of solids or to percentage carry-over. A large amount of work has been done by Hecht and McKinney,[3] Rummel,[4] Powell,[2] and others in an effort to determine the correct factor for use in converting conductance to parts per million of solids. Little success has been met, however, owing to the fact that boiler water compositions vary greatly, and in general a different factor is needed for each specific case, values at wide variance having been used in actual practice. In view of these considerations, it is evident that a more accurate method for determining steam purity is desirable.

The most obvious and direct way to determine steam purity is by evaporating a representative sample of known volume and weighing the residue after drying. Unfortunately, samples of 5 gal. or more are usually required to obtain sufficient solids to weigh accurately, and in the past from 2 to 3 weeks time has been required to evaporate such a sample.

In this paper an evaporation method is described which gives accurate results directly in terms of parts per million of solids present in the steam, which requires little supervision, and which gives results on a 5-gal. sample in from 5 to 7 days.

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[2] S. T. Powell, "Steam Contamination—III, Determination of Steam Quality," Combustion, Vol. 9, No. 5, November, 1937, pp. 25–31.

[3] Max Hecht and D. S. McKinney, "Electrical Conductance Measurements of Water and Steam, and Applications in Steam Power Plants," *Transactions*, Am. Soc. Mechanical Engrs., Fuels and Steam Power, Vol. 53, pp. 139–159 (1939).

[4] J. K. Rummel, "Estimation of Solids in Steam by Conductance," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 3, July, 1931, p. 318.

DESCRIPTION OF TEST METHOD AND APPARATUS

The method consists of evaporating a 5-gal. sample of the uncontaminated condensed steam in a previously weighed platinum dish in the absence of dust. Heated purified air is passed through the bell jar covering the evaporating dish to remove the vapor and to aid evaporation. A control mechanism which prevents the dish from becoming overheated, enables the apparatus to be operated continuously and limits supervision to once a day is included in the set-up. After evaporation is complete, the dish and residue are dried at 105 C. for 1 hr., cooled, and weighed. From the weight of solids present in the known amount of condensed steam, the parts per million of solids in the steam can be calculated.

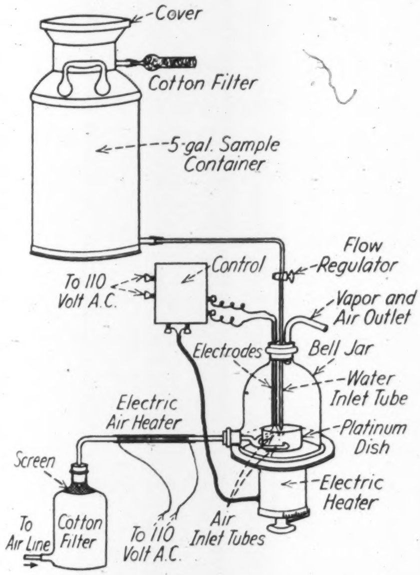
Cover
Cotton Filter
5-gal. Sample Container
Flow Regulator
To 110 Volt A.C.
Control
Vapor and Air Outlet
Electrodes
Bell Jar
Water Inlet Tube
Electric Air Heater
Platinum Dish
Screen
Electric Heater
To Air Line
Cotton Filter
To 110 Volt A.C.
Air Inlet Tubes

FIG. 1.—Evaporation Apparatus.

A sketch of the apparatus employed is shown in Fig. 1 and the wiring diagram of the control circuit is given in Fig. 2. The various pieces of apparatus are as follows:

Sample Containers.—The sample containers were 5-gal. tinned milk cans containing a block tin inlet and outlet. The seams in the bottom of the cans, as well as any scratches or holes through the tin coating, were covered with a high-tin solder.

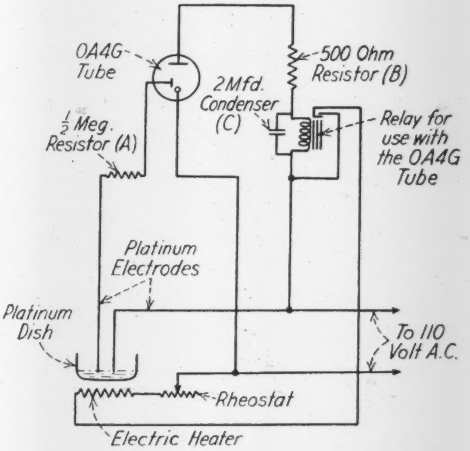
0A4G Tube
500 Ohm Resistor (B)
2 Mfd. Condenser (C)
½ Meg. Resistor (A)
Relay for use with the 0A4G Tube
Platinum Electrodes
Platinum Dish
To 110 Volt A.C.
Rheostat
Electric Heater

FIG. 2.—Wiring Diagram of Control Circuit.

Evaporation Assembly.—The evaporation assembly consisted of a platinum dish mounted on transite and covered with a bell jar through the top of which the water entered the dish through 1-mm. glass tubing and the water vapor and air were expelled through a larger tube. The heated air entered near the bottom of the bell jar through glass tubes constricted and bent in such a manner as to give a swirling motion to the air over the top of the dish. The dish was heated by means of a 250-watt heater, the temperature of which was regulated by means of a manually operated rheostat.

Air Purifier and Heater.—The air was first passed through a cotton batting filter to remove oil, water, and solid matter. It was then passed through the air heater which consisted of a Pyrex glass tube wound with the proper amount of resistance wire to heat the glass just below the softening point when the heating coil was connected to 110 v. alternating current.

Control Assembly.—As shown in Fig. 2, the control assembly consisted of a pair of platinum wire electrodes suspended in the dish at the height at which it was desired to maintain the water level, namely, ¼ to ½ in. from the bottom, a resistor *A* to limit the flow of current through the solution, a relay to operate the heater, and a vacuum tube to amplify the approximately 0.25 milliamperes of current flowing through the solution so that it would operate the relay. Also, a resistor, *B*, and a condenser, *C*, were used to prolong the life of the tube and to improve the action of the particular relay used.

Operation of Apparatus.—In starting the apparatus, the electrodes were first adjusted to the desired position and then, with heated air passing through the apparatus, water from the sample container was allowed to flow into the dish through the capillary tubing until the surface of the water touched the ends of both electrodes. This closed the control circuit which, by means of the relay, supplied current to the heater under the dish. The rheostat on the heater was adjusted so that the temperature of the water in the dish was just below the boiling point. The regulating stopcock was then adjusted so that the rate at which water entered the dish was slightly less than the rate of evaporation. Under these conditions, the water level slowly dropped in the dish until contact with the electrodes was broken and in turn the current to the heater was interrupted. This caused the rate of evaporation to decrease. As soon as the level rose in the dish to the point where the surface touched the electrodes, the cycle of operation was repeated. The rate at which the water entered the dish was adjusted so that current flowed through the heater under the dish most, but not all, of the time. Owing to the fact that as the water level lowered in the sample container the rate of flow of sample into the dish decreased, it was necessary to make an adjustment once each day to reestablish the rate of flow at its original value. As an aid in determining the rate of flow, the end of the entrance tubing was constricted so as to cause the formation of small drops which could be counted, or to give a fine stream the size of which would be indicative of rate of flow. By means of this procedure a 5-gal. sample of condensed steam could be evaporated in from 5 to 7 days.

Conductance Tests.—All conductance readings were taken with flow-type cells containing platinized platinum electrodes. A 60-cycle a.c. conductance bridge was used. The observed conductance was corrected to 25 C. in the usual manner. When a correction was applied for carbon dioxide, 0.6 micromho[2] was deducted from the conductance at 25 C. for each part per million present as determined by titration with standard alkali using phenolphthalein as the indicator. When ammonia was present, 7.4 micromhos[2] was deducted from the conductance at 25 C. for each part per million, expressed as NH_3, present as determined by direct nesslerization according to the method adopted by the American Public Health Association.[5] Such a correction is made on the assumption that the ammonia, calculated as NH_3, was present as ammonium carbonate. No correction was made for the conductance of water.

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[5] "Standard Methods of Water Analysis," American Public Health Assn., Eighth Edition, p. 41 (1936).

EXPERIMENTAL WORK

Accuracy of Evaporation Method:

Two independent methods were employed in determining the reproducibility and accuracy of the evaporation method. In the first, several 5-gal. samples of laboratory quality distilled water of known conductance were evaporated by means of the apparatus described above. As shown in column 9 of Table I, the relation between conductance and solid content of the water was practically constant. In the second method, 5-gal. containers were filled with laboratory quality distilled water which was of the same purity as that used in the first method, that is, the samples were taken from the same storage container. To each sample a weighed amount of dry, reagent-grade potassium chloride was added. The samples were then evaporated and the residues dried and weighed. The difference in the weight of this residue and that of 5 gal. of laboratory quality distilled water as determined in the first test was a measure of the solid added, and, as shown in columns 10 and 11 of Table I, satisfactory agreement was obtained over the range of concentrations tested.

TABLE I.—DATA SHOWING THE ACCURACY AND REPRODUCIBILITY OF THE EVAPORATION METHOD.

Test	Sample	Volume of Sample, ml.	Carbon Dioxide (CO_2), p.p.m.	Ammonia (NH_3), p.p.m.	Observed Conductance at 25 C., micromhos	Corrected Conductance at 25 C., micromhos	Solids by Evaporation, p.p.m.	Solids per Micromho Conductance, p.p.m.	Potassium Chloride Added, p.p.m.	Potassium Chloride Found, p.p.m.[a]
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
No. 1	Distilled water	19 200	2.9	0.0	2.18	0.44	0.30	0.68		
No. 1A	Distilled water as in test No. 1 plus 0.0500 g. of KCl	19 160					2.96		2.61	2.66
No. 2	Distilled water	19 160	3.0	0.0	2.22	0.42	0.27	0.64		
No. 2A	Distilled water as in test No. 2 plus 0.0300 g. of KCl	19 200					1.86		1.56	1.59
No. 3	Distilled water	19 160	2.6	0.0	2.11	0.55	0.37	0.67		
No. 3A	Distilled water as in test No. 3 plus 0.0200 g. KCl	19 200					1.43		1.04	1.06
No. 4	Distilled water		2.8	0.0	2.11	0.43	0.28[b]			
No. 4A	Distilled water as in test No. 4 plus 0.0100 g. of KCl	19 200					0.84		0.52	0.56
No. 5	Distilled water		2.8	0.0	2.08	0.40	0.26[b]			
No. 5A	Distilled water as in test No. 5 plus 0.0050 g. of KCl	19 160					0.49		0.26	0.23

[a] These figures obtained by subtracting the solids found in the distilled water from the solids found in the corresponding sample to which KCl had been added, all as given in column 8.

[b] Estimated from the conductance by use of a factor obtained by averaging the values in column 9.

Determination of Steam Purity:

The steam sample, which was obtained from the outlet steam drum of a boiler which was operating at a pressure of 860 psi., was conducted through stainless steel tubing to a vent-type condenser. The condenser was the type designed and used by the Babcock & Wilcox Co. Two conductance cells were used for all tests and were connected in parallel to the outlet of the condenser by means of pure gum rubber tubing which had previously been washed with a rapid stream of water to remove loose solid particles. The effluent from the two cells was collected in the sample containers for evaporation. Using this procedure, approximately 30 min. was required to fill the sampling container. Conductance readings, temperature readings, and samples for the determination of ammonia were taken at frequent intervals during the sampling period. It was not possible to determine whether free carbon dioxide was present, due to the fact that sufficient ammonia was present to cause the water to give an alkaline reaction to phenolphthalein, but as shown in column 5 of Table II it was assumed that free carbon dioxide was absent.

The solids in the 5-gal. samples of condensed steam, which usually were taken in duplicate, were then determined by evaporation in the previously described manner. These results along with the corresponding conductance data are given in Table II.

TABLE II.—COMPARISON OF THE EVAPORATION AND CONDUCTANCE METHODS FOR DETERMINING STEAM PURITY.[a]

Test	Boiler Water Concentration, p.p.m.	Steaming Rate, lb. per hr.	Volume of Sample, ml.	Carbon Dioxide (CO_2), p.p.m.	Ammonia (NH_3), p.p.m.	Observed Conductance at 25 C., micromhos	Corrected Conductance at 25 C., micromhos	Solids by Evaporation, p.p.m.	Solids per Micromho Conductance, p.p.m.	Solids Based on Conductance Using a Factor of 0.65,[b] p.p.m.
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
No. 1......	47	260 000	19 200	0.0	0.15	2.94	1.85	0.24	0.13	1.21
No. 2......	67	270 000	19 160	0.0	0.14	2.78	1.74	0.19	0.11	1.13
No. 3......	32	270 000	19 200	0.0	0.115	2.15	1.30	0.19	0.15	0.85
No. 3A.....	32	265 000	19 160	0.0	0.115	2.18	1.33	0.22	0.17	0.86
No. 4......	40	265 000	19 200	0.0	0.485	4.82	1.27	0.16	0.13	0.83
No. 4A.....	40	265 000	19 160	0.0	0.485	4.58	1.03	0.17	0.16	0.67
No. 5......	37	355 000	19 200	0.0	0.40	3.97	1.09	0.46	0.42	0.71
No. 6......	158	220 000	19 160	0.0	0.29	3.40	1.26	0.43	0.33	0.85
No. 7......	655[c]	380 000	19 160	0.0	0.62	5.29	0.82	1.01	1.23	0.53
No. 8......	932[c]	362 000	19 200	0.0	0.68	5.55	0.66	0.71	1.08	0.43

[a] All tests were made on condensed steam from a boiler operating at a pressure of 860 psi. and a final steam temperature of 900 F. The steam leaving the boiler is washed by spray-type steam washers.

[b] This factor was used because it agrees well with those being used by other investigators and also because it agrees well with those given in column 9 of Table I.

[c] The solids in the sample consisted largely of sodium sulfate.

DISCUSSION AND CONCLUSIONS

The results presented in columns 10 and 11 of Table I indicate that the evaporation method gave accurate results when used to determine the amount of potassium chloride added to 5-gal. samples of distilled water of known solids content. The slight inconsistencies in the results are thought to have been due mainly to errors in weighing the platinum dish in which the water was evaporated. These dishes were quite thin and therefore had large surfaces in proportion to their weight. Slight differences in the temperature of the dish and the atmosphere would therefore cause an appreciable error in the weight of the dish. Also, an appreciable error was made owing to the picking up of moisture by the dish and contents during the weighing process. Other slight errors were perhaps caused by solids adhering to the electrodes and to small rust spots developing in the tinned sample containers.

After each test, an attempt was made to remove any material adhering to the electrodes. In most cases the weight of the material was negligible, but in case an appreciable amount was present, its weight was added to that of the residue in the dish. The fact that slight rusting occurred in the milk cans, which were selected for use because they were inexpensive and portable, indicates that these containers are not entirely satisfactory for such determinations. Still better results would probably have been obtained if tinned copper or pure block tin containers had been used.

The fact that the values in column 9 of Table I, for the amount of solids equivalent to one micromho conductance, were practically constant indicates that in the absence of ammonia the conductance method may be expected to give satisfactory results, provided the conversion factor is determined by the evaporation method. This fact is illustrated by the data for tests Nos. 4, 4A, 5, and 5A, in which the sum of the solids originally present in the distilled water, as determined by conductance (using an average of the factors in column 9), and the added solids was found to be in agreement with the total solids as determined by evaporation. The fact that conversion factors of wide variance have been obtained by different investigators indicates that it is necessary to determine the factor by use of evaporation and conductance data for each specific case if accurate results are to be obtained by the conductance method. Even then, in the absence of ammonia, results obtained by use of the conductance method are usually questionable, due to the carbon dioxide and temperature corrections and to errors in determining the cell constant.

The results in Table II give a comparison of values obtained for the purity of steam from a boiler by the evaporation and conductance methods. The values obtained by the evaporation method, which in view of the results given in Table I and those of other investigators[2] are considered quite accurate, were in all cases at variance with those obtained by the conductance method. This was thought to be due to errors in the conductance method caused mainly by the large amount of ammonia in the steam and the inability to determine and thus apply the proper corrective factor for this gas. These errors may have been due to two causes: the presence of ammonia in a form other than ammonium carbonate as assumed, and the presence of carbon dioxide which could not be detected by the usual method due to the presence of ammonia. Thus, if some of the ammonia were present as ammonium hydroxide or ammonium sulfate rather than as ammonium carbonate, a different correction would have to be applied. No attempt was made to determine whether this was the case or to determine whether free carbon dioxide was present, it being assumed as shown in column 5 of Table II that no free carbon dioxide was present.

As shown by the results in column 10 of Table II, the relation between corrected conductance and solids content of the steam as determined by the evaporation method was not constant. This was thought to have been due largely to the inability, as discussed above, to correct accurately for the large amount of ammonia present. The conductance method, even if calibrated by the evaporation method, would therefore not be expected to give accurate results under such conditions. The evaporation method, however, which is unaffected by dissolved gases, gave consistent results.

In all of the tests carried out in this investigation, 5-gal. samples were evaporated in order to obtain sufficient solid matter to give a high degree of accuracy. If such a high degree of accuracy is not required or if more solids are present in the steam, the size of the sample may be decreased, thus proportionately decreasing the time of evaporation.

DISCUSSION

Mr. D. S. McKinney[1] (*presented in written form*).—The apparatus devised by Mr. Ulmer is a very considerable improvement over that usually used for the purpose. The disadvantage of an extremely large sample and consequent long time for analysis is obvious. The use of a semimicro method, allowing weighing to 0.01 mg., would permit reducing the sample size to 0.5 gal. with the same relative accuracy as obtained by Mr. Ulmer and with considerable saving in time. A good quality analytical balance can be made sensitive to 0.01 mg. as follows:

A plano-convex galvanometer lens of 1-m. focal length is silvered and shellacked on the flat side. The lens is then attached in a horizontal plane, silvered side down, to the center agate bearing of the balance by means of a bit of wax, and the pointer bob lowered until the balance is again stable. The top glass of the balance is replaced by a piece of plate glass. A plane mirror is then located so that the distance from the lens to the mirror and back to the balance base is five times the length of the pointer. A single-filament lamp is then located above the balance so that the light reflected from the lens is reflected back from the plane mirror to the base of the balance, where, by proper adjustment of the lamp and mirror, an image of the lamp filament can be received on a piece of graduated paper placed on the base of the balance. The deflection of the filament image will be ten times the deflection of the pointer. The rider is then replaced by one of one-tenth the weight, and fractional weights used down to the weight of the smaller rider.

The use of the semimicro procedure would allow the use of a platinum-lined sample container instead of the tin-lined container used by Mr. Ulmer. In my opinion, the poor results reported in Table II are due mainly to the attack of the alkaline water on the tin-lined sample can. Although one must admit the possibility of error in all the measurements made and that ten sets of data are rather few when three variables are to be considered, a fairly good case can be made for this opinion.

If the observed conductance, L, is a linear function of solids by evaporation, S, and the ammonia, N, as is assumed in the paper, then the results may be represented by the equation:

$$a \cdot S + b \cdot N = L \text{ or } a \cdot \frac{S}{L} + b \cdot \frac{N}{L} = 1$$

If $\frac{S}{L}$ is then plotted against $\frac{N}{L}$, one should obtain a straight line with positive intercepts on both axes. If b is not a constant but a function of the ammonia content, one should still obtain on the above plot a regular curve with positive intercepts. Instead, one obtains a shotgun diagram from which no conclusion can be drawn. However, if one plots the ammonia against the observed conductance, a fairly smooth curve can be drawn through the points, indicating that the conductance is mainly due to ammonia. If the contribution of the dissolved solids to the conductance is calculated using the factor preferred by the author, this contribution deducted from the observed conductance and the result plotted against the ammonia content, the points scatter worse than in the plot of ammonia *versus* observed conductance. In my opinion, this is due not to variability of the ratio of dissolved solids to conductance but to increase in solids content of the water caused by attack of the alkaline water on the tin-lined sample container.

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[1] Assistant Professor of Chemistry, Carnegie Institute of Technology, Pittsburgh, Pa.

The suggested semimicro procedure would save time and eliminate these difficulties.

MR. MAX HECHT.[2]—The closed evaporating system described lends itself to direct use in the power plant without the necessity of transporting large volumes of water in containers. Some simple form of orifice metering equipment can be applied for measuring the volume of condensate. Sampling and cooling equipment using stainless steel obviates the uncertainty of coatings. The inclusion in the sample of foreign metals such as iron from such a system would be negligible or could be determined in the evaporated residue and corrected for.

The author mentions imperfections in the tinned coating exposing iron spots. It is apparent therefore that some tin has been introduced into the sample in the form of SnO_2 and no corrections for the "total" solids due to this inclusion have been made.

The calibration of the conductivity method by a weight method is fundamental and in this connection all of the necessary factors for correction of the weighed residue as well as the conductivity determination must be applied. For example, the weighed residue must be corrected for substances lacking electrical conductivity characteristics. Among these are SiO_2, Fe_2O_3, Al_2O_3, and organic matter. Similarly, the conductivity measurement should be corrected for conductivity of gases such a CO_2, NH_3, and H_2S. The assumption that the ratio of evaporated residue to conductivity is a constant is incorrect. It appears that investigators subsequent to Powell's publication have assumed that Hecht and McKinney formulated this mode of expression. Powell[3] states: ". . . Hecht and McKinney indicate a calibration of about 0.5 p.p.m. per micromho." A critical reading of the Hecht-McKinney paper[4] fails to disclose that any attempt was made by them to establish any such ratio. Further, a careful reading of Hecht and McKinney's closure to their paper supplies the definition for "dissolved salts" and it is this quantity which was calculated from conductivity.

It is suggested that ammonia correction be developed for each plant by preparation of a synthetic boiler water solution to which is added known amounts of ammonia in a manner similar to the method described by Hecht and McKinney for CO_2. In my opinion this suggestion avoids the analytical errors in determining minute amounts of ammonia or of dissolved salts.

It is still doubtful, in my opinion, that a constant factor can be used to correct ammonia and CO_2 to conductance in order to make the necessary gas corrections. The data in Rummel's paper[5] substantiates this opinion in the case of CO_2. In conclusion, the author has apparently overlooked the fact that the method of mixture of concentrated water with steam condensate offers the most suitable method of calibrating the conductivity data. This method has been used with dependable results by Fitze,[6] Rummel,[5] and Hecht and McKinney.[4]

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[2] Adviser, Power Stations Chemistry, Pittsburgh, Pa.

[3] Sheppard T. Powell, H. E. Bacon, Jr., I. G. McChesney and F. Henry, "Design and Development of Apparatus for Measurement of Steam Quality by Electrical Conductivity Methods," *Transactions*, Am. Inst. Chemical Engrs., Vol. 33, March 25, 1937, p. 116.

[4] Max Hecht and D. S. McKinney, "Electrical Conductance Measurements of Water and Steam, and Applications in Steam Power Plants," *Transactions*, Am. Soc. Mechanical Engrs., Fuels and Steam Power, Vol. 53, pp. 139–159 (1931).

Mr. E. Mandel.[7]—Our apparatus is very similar to that of Mr. Ulmer. However, we found the manually controlled regulator of the flow of water to the platinum dish to be unsatisfactory. The apparatus could not be used with safety during the night when there was no one to regulate the operation; a slight increase in the rate of flow would cause the water to overflow the dish. The manual flow regulator was replaced by a magnetic (solenoid) valve which maintains a constant water level in the dish by automatically opening and closing the water line. With this modification, both the water flow and the heat are automatically controlled, and the apparatus can be operated continuously (both day and night) with practically no attention once it has been set up and put in operation.

A Member.—Is there any correlation between the old method of determination and the control method on identical water? Have you taken a particular water and run the old evaporation method without the control system you just spoke of, and also run the same water in your control system?

Mr. Mandel.—We have no data on that.

Mr. J. B. Romer.[8]—During the period since J. K. Rummel made his early study of the conductivity of steam condensate and established the relationship between solids in steam and the conductivity of the steam condensate, we have had the opportunity of examining steam condensate from a number of boilers. As Mr. Ulmer points out, ammonia is a source of trouble in converting the conductivity value to parts per million of solids. In most cases, we have been very fortunate in obtaining a satisfactory correction factor by the aid of Rummel's curves for ammonia correction.

In a number of cases we have made a thorough investigation of the total solids by evaporation of a large sample of steam condensate. The samples have been collected both in Pyrex and also in heavily tinned milk cans, as shown by Ulmer, and we have consistently found that the milk-can sample always shows some H_2S metals to be present, and the samples in Pyrex always show a little higher silica. There is always a little tin in spite of everything. We had some trouble from rust spots in the first sample; then we bought a milk can and sent it back to the tinner with the request that he put two, three, or four coats on until he had a coating that would not break through. Since then, we have not had any trouble with rust spots on the inside of that can.

Mr. R. C. Ulmer[9] (*author's closure by letter*). Mr. McKinney's suggestion that a semimicro procedure which would permit the use of a smaller sample be employed is a good one, but, as he has suggested, a good quality analytical balance must be used. It is probable that most balances available in power plants are not of sufficient precision to warrant the use of such a sensitive method of observing swing of the balance pointer. At any rate, if such a balance were available and his suggested apparatus were used, it would be necessary to make the weighings in a constant-temperature room, as difficulty was encountered in this work in accurately weighing the platinum dish with an ordinary balance because of the effect of slight changes in temperature of the dish which had a rather large surface. Use of such a room would complicate the method to such an extent that it would be impractical for use, and for this reason the use of a larger sample and its resulting greater amount of solids is recommended.

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[5] J. K. Rummel, "Estimation of Solids in Steam by Conductance," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 3, July, 1931, p. 318.

[6] M. E. Fitze, "Determination of Moisture in Steam by Electrical Conductivity," *Power*, September 18, 1928, pp. 484–485.

[7] Commonwealth Edison Co., Chicago, Ill.

[8] Chief Chemist, The Babcock & Wilcox Co., Barberton, Ohio.

[9] Chemist, Research Dept., The Detroit Edison Co., Detroit, Mich.

In the case of the results given in Table II, Mr. McKinney concluded from his proposed equation that the observed conductance, column 7, was not a linear function of the amount of solids obtained by evaporation, column 9, and the amount of ammonia, column 6. This was indicated, as pointed out in the paper, by the fact that the factor, column 10, relating solids by evaporation to conductance corrected for ammonia, was not constant and did not show a definite trend. That this was the case was not necessarily due to the reason given by Mr. McKinney, namely, that metal was dissolved from the sample cans but may have been and probably was due, as pointed out in the paper, to variation in the form in which the ammonia existed in the water. Thus, if the ammonia in one test were present as ammonium hydroxide, a correction factor of 9.1 micromhos per p.p.m. present as NH_3 would be required, whereas, if in another test the ammonia were present as $(NH_4)_2CO_3$, a factor of 7.4 micromhos per p.p.m. present as NH_3 would be required, and if in another test the ammonia were present as $(NH_4)_2SO_4$, a factor of 5.8 micromhos per p.p.m. present would be required. As in this work, boiler water compositions varied considerably, it is probable that the form in which the ammonia was present in the condensed steam varied, and, as to the author's knowledge there is no simple way of determining the form in which small amounts of ammonia are present in steam, the more or less conventional factor of 7.4 micromhos per p.p.m. of NH_3 was used. It is evident that a so-called "shotgun diagram" would be obtained as a result of the inability accurately to correct for the ammonia present. Evidence that the lack of agreement between the two methods is the result of this fact, rather than to solution of metal from the cans as Mr. McKinney suggested, is given by the fact that when ammonia was absent from the solutions as in the tests given in Table I in which tests the same cans and apparatus were used, the factor relating the amount of solids by evaporation to corrected conductance was constant. It is not thought that the slight difference in alkalinity of the solutions used in the two tests would cause such a marked effect on the cans, and, at any rate, if such were the case the effect should be more or less constant or at least show a definite trend. Further evidence in favor of the results obtained by evaporation is given by the fact that in Table II, column 9, the results obtained by evaporation vary in direct proportion to the boiler water concentration as would be expected, whereas in column 11 the results based on conductance vary indirectly with the boiler water concentration which is not to be expected.

As Mr. Hecht suggested, the apparatus described could be used in the power plant, thus avoiding transporting the samples. Regarding his objection to the use of coated containers, as pointed out in the paper some difficulty was encountered in the use of tinned iron cans. Since the paper was presented, aluminum cans have been used in subsequent tests. At first considerable aluminum was dissolved from these cans, but after being filled with the water for several weeks use of the cans was found satisfactory and only a trace of aluminum dissolved during a test. Use of annodized aluminum cans probably would be a still greater improvement.

Regarding Mr. Hecht's objection to the fact that no correction was applied for any non-conducting substances present, in calibrating the conductance method by the evaporation method it should be pointed out that such a correction is not always desirable. Thus, in most cases the total solids rather than the dissolved solids are desired in steam purity tests. In this respect it is thought best to assume that the amount of non-conducting solids, which usually are present in small amounts, is constant as was done in the paper. If this is done, the results obtained by the conductance method indicate total solids rather than dissolved solids.

Mr. Hecht's statement that the ratio of evaporated residue to corrected conductance is not constant is entirely correct. As the results of an evaporation method are in terms of total solids, which is desirable, the error must lie in the conductance method. For this reason, use of the evaporation method, which gives results directly in the desired terms, is to be advocated.

It is the opinion of the author that an ammonia correction cannot be developed by preparation of a synthetic boiler water solution to which known amounts of ammonia are added in a manner similar to the method described by Hecht and McKinney for CO_2 for the reason that, as stated previously, it is not readily possible to determine the form in which the ammonia is present in the steam, and for this reason it would not be possible to add the correct form of ammonia to the synthetic boiler water.

Regarding Mr. Mandel's statement that some difficulty was encountered by them in controlling the rate of flow of water into the dish in a similar apparatus, some difficulty along this line was also encountered in this work. Our experience was, however, that the rate usually decreased rather than increased and that the time required to evaporate the sample was increased.

Recently a device for automatically controlling the flow of water into the dish was added to the apparatus. By means of this modified apparatus the time required to evaporate a 5-gal. sample has been reduced from 7 to 4 days.

Regarding Mr. Romer's statement that in most cases they have been able to correct satisfactorily the conductance of condensed steam by use of Rummel's curves, we also have been able in some cases to obtain "reasonable" results by use of a factor similar to that obtained from his curves. Whether these results were accurate or just "reasonable" is another question. In other cases as in the case of those given in Table II the results based on conductance measurements were not "reasonable" in that the apparent amount of solids in the steam was greater at low boiler water concentrations than at higher ones. Thicker coatings of tin over the sample containers were also tried, but in time rusting occurred. For this reason aluminum cans were tried and so far have proved superior to the tinned ones.

ELECTRICAL CONDUCTANCE MEASUREMENTS OF WATER EXTRACTS OF TEXTILES

By A. C. Walker[1]

Synopsis

It has been shown that the electrical properties of textiles depend upon chemical composition, water-soluble electrolytic impurities, moisture content and manner of drying the material from the wet state. Selection of a textile for electrical purposes should include consideration of the influence of chemical composition upon the properties of the material, absence of significant amounts of electrolytes, and the method of drying the material from the wet state.

This paper discusses the water extract conductivity method, its correlation with insulation resistance data, and describes a simple, durable electrolytic cell which is convenient to use for the conductivity measurements.

The electrical properties of a textile depend upon its chemical composition, the amounts of moisture and water-soluble electrolytic impurities held in the fiber structure,[2] and also upon the manner of drying the material from the wet state.[3] Marked improvements in the electrical insulation resistances of such textiles as cotton and silk have resulted from washing the material in water.[4] In this way the naturally occurring water-soluble electrolytic salts are removed from the cotton structure, and certain electrolytic materials introduced during processing are removed from silk.

Methods of Measuring Effectiveness of Water Washing:

Two methods have been used for testing the quality of washed textile insulation since its introduction into telephone apparatus more than ten years ago. The first is a measurement of d.c. insulation resistance of threads of the textile when stretched between parallel electrodes and conditioned for several hours in an atmosphere of controlled humidity and temperature. The resistance of such a textile is determined by the paths of moisture within the structure of the fibers along which the electrical current flows, and the resistance along such paths is influenced by the kind and amount of electrolytic impurities which may dissolve in this adsorbed moisture.[2] Thus the insulation resistance test measures the net effect of moisture and electrolytic impurities. This method has been described in a previous publication.[5]

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[1] Member of Technical Staff, Bell Telephone Laboratories, New York City.

[2] E. J. Murphy and A. C. Walker, "Electrical Conduction in Textiles—I," *Journal of Physical Chemistry*, Vol. 32, p. 1761 (1928).

[3] A. C. Walker, "Moisture Content and Electrical Conductivity of Cotton," *Journal*, Textile Inst., Vol. 24, p. 145 (1933).

[4] R. R. Williams and E. J. Murphy, "Influence of Moisture and Electrolytic Material upon Textiles as Insulators," *Journal*, Am. Inst. Electrical Engrs., Vol. 48, p. 568 (1929).

The second method is a measurement of the a.c. conductance of a water extract of the textile. A known weight of sample is boiled in a measured volume of distilled water under controlled boiling conditions, the water decanted off, made up to a fixed volume, and measured for electrical conductivity at constant temperature.

The insulation resistance test has been employed as a minimum specification requirement for inspection and control purposes in the commercial purification of silk and cotton for telephone apparatus, primarily because it gives a direct measure of the net improvement secured by washing and drying. The water-extract conductivity test, although not giving a measure of the total insulating improvement obtainable and therefore being less suitable as an end requirement than the insulation resistance test, is considered to be of great importance as a supplementary method since it gives a measure of the amount of water-soluble electrolytes which are particularly harmful in insulation due to their marked corrosion effects. In addition, this test helps to evaluate separately the factors which contribute to the improved insulating qualities of textiles secured by washing.

Other investigators[6] have reported the use of this extract method as an inspection test, claiming that it is less troublesome and requires less time than the insulation resistance test, and that it renders unnecessary the precise temperature and humidity control required in the resistance measurement. From our experience with both methods it is concluded that the extract test possesses no material advantage over the insulation test as regards difficulty or time, but the equipment required may be somewhat less expensive.

Before describing this extract conductivity test and a simple, rugged type of cell developed for this purpose, it may be well to give some consideration to the factors involved in securing optimum electrical insulation resistance properties in textiles, particularly cotton, in order to evaluate the merits of both test methods.

TABLE I.—PROPERTIES OF COTTON.
85 per cent relative humidity, 100 F.

Drying Treatment	Moisture Content, per cent	Insulation Resistance, kilomegohms of a thread 3/4 in. long	Specific Conductivity of Water Extract, micromhos per g.
Sample A:			
Oven-dried.....	10.35	31	16
Air-dried	11.20	12	17
Sample B:			
Oven-dried.....	10.25	29	19
Air-dried.......	11.10	13	20

Textile Properties Affecting Test Results

Cotton will exhibit different moisture adsorbing capacities depending upon the previous treatment of the material, particularly the conditions under which it is dried from the wet state. If washed cotton is air-dried at room conditions from a thoroughly wet state it will thereafter adsorb more moisture at any given equilibrium humidity condition than if the same material is oven-dried at temperatures above 100 C. In fact, the higher the temperature of drying, within safe limits as regards the stability of the fiber, the lower will be the moisture adsorbing capacity of the textile.

Table I illustrates this characteristic of cotton.

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[5] H. H. Glenn and E. B. Wood, "Purified Textile Insulation," *Transactions*, Am. Inst. Electrical Engrs., Vol. 48, April, 1929, p. 576.

[6] J. Van Laetham and R. Vernimmen, "Inspection of Textiles Used in the Manufacture of Telephone Cords and Cables," *Electrical Communication*, Vol. 14, p. 35 (1935).

Before washing, these materials had an insulation-resistance value of the order of 0.15 kilomegohms per thread, and a water-extract conductivity of 180 micromhos per gram. Washing alone, as measured by the air-dried insulation resistance, caused an improvement of about 100-fold; oven-drying more than doubled this result.

Thus it is seen that the insulation resistance of cotton may be improved between 100 and 200-fold by proper washing and drying. Under optimum conditions, this improvement may be as much as 250-fold. Of this total, a large part is the result of the removal of water-soluble, naturally occurring electrolytes by the washing treatment, and this is therefore termed *electrolytic* improvement. The remainder of the improvement is due to the method of drying, and it has been suggested that this drying when carried out to the best advantage as regards the electrical properties of the material, causes a reduction in the capacity of the internal surfaces of the fibers to adsorb moisture. Therefore it is termed *structural* improvement.

The insulation resistance of cotton, however, is to some extent diminished when well-washed and well-dried material is exposed in a loose state to cyclic changes in atmospheric temperature and humidity conditions over an extended period of time. Until recently it was considered that this drying effect might be a transient one. The following test, one of several which have been made, shows that the structural improvement is largely retained under certain conditions easily achieved commercially.

Effect of Atmospheric Conditions on Purified Material:

Two samples of red-dyed cotton were taken from a package of washed material. About two ounces were wound, while still wet, upon each of two paper tubes. One of these samples was air-dried at room conditions, the other oven-dried above 100 C. After drying, these two samples had insulation resistances, designated Initial Insulation Resistance in Table II.

Again in this table it is seen that oven-drying gives resistance values more than twice those of air-drying. These two samples were left on a table exposed to sunlight and atmospheric conditions, but protected from dirt, for 6 months. After this time the red dye showed some fading on the sides of the packages exposed to the sun. They were then stored in a loose-fitting pasteboard box for 5 yr. The outside layer on each package was then measured for insulation resistance giving the values opposite test length No. 1 in the table. Thus it is seen that the resistances of these outer layers were reduced to about 38 per cent of the initial values. After removing successive test lengths up to a total of 90 ft., the insulation resistance values approximated the initial ones, even though

TABLE II.—INSULATION RESISTANCE TESTS ON COTTON AFTER 5-YR. EXPOSURE TO ATMOSPHERIC CONDITIONS.

Test Length	Length of Thread Removed Referred to End on Outside of Spool	Insulation Resistance, kilomegohms per thread, 3/4 in. long. at 85 per cent relative humidity, 100 F.	
		Air-dried	Oven-dried
Initial insulation resistance taken after drying	....	14	31
No. 1	0 to 15 ft.	5.5	11.5
No. 2	15 to 30 ft.	5.9	15
No. 3	30 to 45 ft.	6.7	16
No. 4	45 to 90 ft.	7.0	21
No. 5	60 to 75 ft.	9.0	27
No. 6	75 to 90 ft.	10.0	29
No. 7	Total of 80 yd. removed	14	31

faded spots were still visible on the sixth test length. After unwinding a total of 80 yd. from each spool the original insulation resistance values were shown to be retained.

Even superficial protection of a well-dried textile as illustrated by this test is sufficient to preserve the initial high insulating quality. It would appear that the underlying layers, even when not fully protected from the atmosphere, may be sufficiently firmly held in place so that cyclic changes of humidity may not seriously impair the value, as is the case with material loosely exposed. Thus the layer of insulation on a textile insulated wire next to the conductor may retain its initial high quality after a period of years if it is not adversely affected by prolonged, complete exposure between the time of drying and the application of insulation. It also should be noted, as discussed in detail in a previous paper[3] that a high initial insulation resistance can be again secured with a cotton such as the air-dried sample in Table II by rewetting the material with liquid water and redrying rapidly at a high temperature, for example, the treatment initially accorded to the oven-dried sample in Table II.

In the light of these experiments, it is emphasized that the improvement which may be obtained by optimum drying of well-washed cotton is important since it may be retained to a large extent, if not completely, during the life of the insulation. Even if not entirely retained, the data in Table II show that the better the initial drying, the higher is the general level of insulation resistance, even if the material is later exposed to the normal variations in atmospheric humidity conditions.

Based on these data, it is clear that more than one test method is necessary to evaluate the insulating quality of the material. Two samples of cotton may have the same insulation resistance, but may have different degrees of purity as measured by the water-extract test. Conversely, two samples of the same purity may have different insulation resistance values depending upon the manner of drying the material from the wet state and the subsequent exposure to varying atmospheric conditions.

Therefore, to determine the insulating quality of a washed textile it is first necessary to determine its purity by the extract measurement. Then, if the material has been adequately protected from high atmospheric humidity conditions subsequent to drying, the insulation resistance measurement gives an indication of the improvement effected by the drying procedure. However, if the textile has been exposed to unknown atmospheric conditions subsequent to drying it is necessary to rewet the material and oven-dry it at a temperature of 105 C. and again measure the insulation

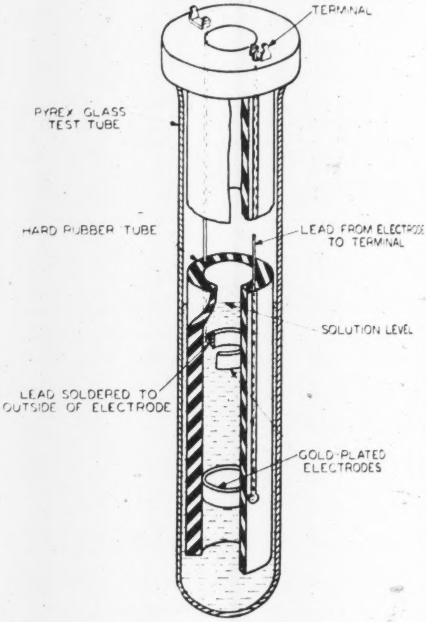

FIG. 1.—Conductivity Cell.

resistance. These two resistance measurements give sufficient information to characterize the insulating properties of the material. However, in practice, the method of sampling washed and dried cotton avoids the effect of atmospheric humidity, and with some knowledge regarding the general level of insulation resistance of washed textiles the single insulation resistance measurement of the material furnishes sufficient information to characterize the efficiency of the drying procedure.

Water-Extract Method:

A simple, durable conductivity cell that has been used in our laboratories for some years for measuring the water extracts of textiles is shown in Fig. 1. It consists of a hollow, hard-rubber tube, $8\frac{1}{2}$ in. long by $1\frac{1}{4}$ in. in outside diameter and $\frac{3}{4}$ in. in inside diameter, surmounted with a cap upon which are mounted two terminal lugs. This cell is shown inserted in a Pyrex glass test tube 9 in. long by $1\frac{5}{16}$ in. in inside diameter which contains the test solution. The top of the cell is drilled out so that the tube is open from end to end. Inside this tube at distances of 1 in. and 3 in., respectively, from the bottom end are fitted tightly two gold-plated copper rings $\frac{1}{4}$ in. wide, made from $\frac{3}{4}$-in. outside diameter copper tubing, with a wall thickness of approximately $\frac{1}{64}$ in. These rings constitute the electrodes and are firmly forced into the positions shown. Flexible copper leads buried in the wall of the rubber tube connect the terminal lugs with these rings. Thus the cell consists of two gold-plated electrodes mounted coaxially in a hollow insulating tube, and when the cell is immersed in a solution containing enough liquid to cover both rings, the liquid rises to the same height inside the tube as outside. Placing the electrodes on the inside of the tube restricts the current flow to the cross-section of solution between the two rings, thus making the measurement independent of the shape of the vessel containing the solution. With the usual type of glass dip cell, this same effect is accomplished by a glass shell or "petticoat" placed around the electrodes.

This cell is considered to have several advantages. It is durable, and can be reproduced readily to exact physical dimensions so that the cell constant for different units may be substantially the same. Three cells made up at different times from the same blueprint gave cell constants all between 1.86 and 1.87. Another important advantage is the fact that after making a measurement on a highly contaminated sample extract, the cell can be removed, dipped in distilled water, and the excess liquid adhering to the cell blown off with compressed air. This method of removal of liquid is a mechanical drying rather than drying by evaporation; thus there is less chance of contamination than where the electrodes used are platinized platinum which might retain traces of electrolytes adsorbed in the spongy platinum surfaces unless proper care is taken to wash these electrodes well between tests. The electrode rings in the hard-rubber cell fit tightly against the inner wall of the tube so that liquid cannot be trapped behind the electrodes. Because of the ease of cleaning and drying of the cell, the time required per test is a minimum.

The limiting factor in determining the accuracy and reproducibility of a water-extract conductivity test of textile insulation is considered as being the uniformity of extraction, rather than electrode polarization effects which may be somewhat greater for polished electrodes than for platinized platinum electrodes. Therefore, for commercial purposes such as for process investigation or control where dilute aqueous solutions are concerned, this cell is particularly satisfactory. Also it is considered that it should be useful in laboratory instruction in educational institutions where research precision is not required.

The possibility of contamination due to sulfur bloom and sulfuric acid formation on the rubber surface appears to be negligible, particularly if the cell is kept in water except when in use. No significant change has been observed in the surface of the rubber on a cell which has been in use nearly ten years. Replating of the electrodes is desirable after a period of a few years.

Test Procedure for Water-Extraction of Textiles:

A recommended test procedure for textiles is as follows:

A 0.5-g. sample of textile or other fibrous insulating material is cut into small pieces about ¼ in. in largest dimension, and placed in a 250-ml. Pyrex beaker. One hundred milliliters of boiling distilled water is added, and the beaker covered with a watch glass, and the mixture boiled gently for 10 min. Boiling should be carefully controlled in such a way as to cause currents which will maintain a circular motion of the material. A most satisfactory type of heater is one with a coiled heating element exposed directly below the beaker, and with an adjustable rheostat for temperature control. These individual heaters are more satisfactory than a large hot plate which may accommodate a large number of beakers, since differences in temperature at different points on the surface may seriously affect the efficiency of the extraction.

After boiling for 10 min. the water is decanted off and the procedure repeated. These two extracts are combined and brought to a volume of 150 ml. Sixty milliliters of this extract are placed in the Pyrex test tube and this in turn is placed in a water bath at 77 F. (25 C.). After the extract reaches equilibrium, both as regards temperature and absorption of atmospheric carbon dioxide, the dry conductivity cell is inserted in the solution and the conductance measured. A blank on distilled water is made, the water being given the same boiling treatment as in the case of an extraction. It is considered unnecessary to describe the actual electrical measurement or the theory involved since this is available in any physical chemistry text. It is, however, preferable to use an alternating current of relatively high frequency, say 1000 cycles per second, so as to minimize electrolytic polarization effects.

TABLE III.

Weight of Sample, g.	Extraction Procedure, each with 100 ml. H_2O, total volume at end 150 ml.	Specific Conductivity, micromhos per g. at 77 F.
0.1	Two 10-min. boiling periods	38
0.3	Two 10-min. boiling periods	35
0.5	Two 10-min. boiling periods	33
0.5[a]	Two 10-min. boiling periods	35
0.5[a]	Two 10-min. boiling periods	34
0.8	Two 10-min. boiling periods	29
1.0	Two 10-min. boiling periods	28
1.0	Three 10-min. boiling periods	28
1.0	One 5-min., one 3-min., one 3-min. boiling period	27
1.0	One 5-min., one 1-min., one 1-min. boiling period	27
Blank on distilled water		4.3

[a] Check analysis.

Table III illustrates the effect of size of sample as well as several extraction procedures.

In this table, all measurements are converted to a comparable basis to observe the effect of sample size. For example, the actual total specific conductivity for the 0.1-g. test was 8.1 micromhos. Subtracting the blank of 4.3 gives a value of 3.8. This observed value is divided by the weight of the sample, giving 38 micromhos per gram.

In view of the fact that it would be exceedingly difficult to extract all of the water-soluble electrolytes from a textile sample, a method such as that described here is, of course, somewhat arbitrary. Therefore it is considered less important to specify rigidly the size of sample and volume of solution than to be explicit about the reproducibility of the test conditions whatever size of sample and volume of solution is selected for a given purpose. We have found it convenient to use 0.5 g. of sample and two 10-min. extractions.

Bulk of sample becomes a factor for a given volume of water as the sample size is increased much above 1 g., since the effectiveness of extraction is decreased and somewhat variable results are observed due to lack of uniform agitation during boiling.

Conclusions:

The d.c. insulation resistance of a washed textile, particularly cotton, is dependent upon its impurity content, the capacity of the material to adsorb moisture, and the distribution of such moisture on the internal surface of the material. This moisture content and distribution in turn is dependent upon the manner in which the material has been previously dried, as well as its subsequent exposure to cyclic humidity conditions. It is clear, therefore, that a single test such as insulation resistance or water-extract conductivity is not sufficient alone to characterize the electrical insulating quality of the material. A combination of the above tests together with some background of knowledge of the general level of insulation resistance of the material provides a means of obtaining a better picture of the quality of the textile and a means of insuring control of the process used to secure satisfactory commercial material

DISCUSSION

Mr. W. D. Collins.[1]—The accompanying Fig. 1 shows a dipping type conductivity cell made of lucite (a transparent plastic) which is being used by the Geological Survey in the field and in the laboratory. It obviates the trouble and loss of time due to breakage of glass cells. The cell, which is of the same size as the usual dipping cells, was made in the instrument shops of the Geological Survey in the steps shown in Fig. 1. A cylinder of lucite is used instead of a glass cylinder to hold the sample for measurement of conductivity.

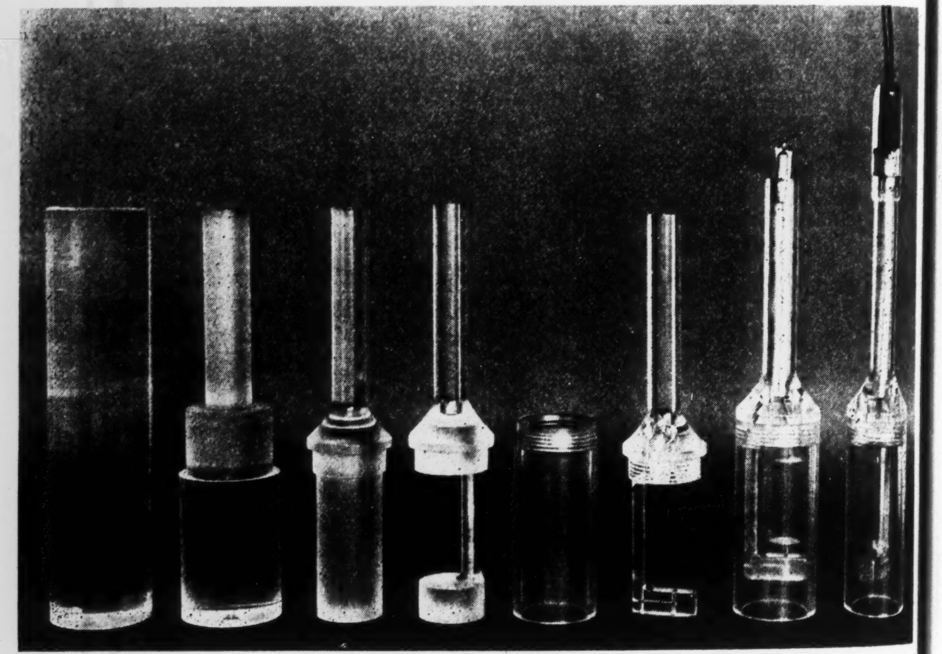

Fig. 1.—Dipping Type Conductivity Cell.

The Chairman (*Mr. E. P. Partridge*[2]).—I should like to ask Mr. Walker one question, that is, whether the gold electrodes are located inside of the tube by actually forming the tube around the electrodes, or are they pushed in.

Mr. A. C. Walker.[3]—In this particular cell the electrodes were gold-plated brass rings pressed into place on the inside of the tube. No doubt a better job could be done by molding the rings into some resistant plastic material or hard rubber, but the degree of contamination by liquid which might be trapped behind the pressed-in rings is shown by test to be negligible. An important advantage of this cell is that the wet surface may be dipped in distilled water to reduce contamination and then blown dry with compressed air. In this way most of the adhering liquid is mechanically removed and does not leave dried spots of electrolyte.

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[1] Chemist in Charge, Quality of Water Division, U. S. Geological Survey, Washington, D. C.

[2] Director of Research, Hall Laboratories, Inc., Pittsburgh, Pa.

[3] Member of Technical Staff, Bell Telephone Laboratories, Inc., New York City.

This cell is not unique, perhaps, but it has the merit of simplicity and it gives excellent results for commercial purposes.

THE pH, DISSOLVED IRON CONCENTRATION AND SOLID PRODUCT RESULTING FROM THE REACTION BETWEEN IRON AND PURE WATER AT ROOM TEMPERATURE

By Richard C. Corey[1] and Thomas J. Finnegan[1]

Synopsis

A study was made of the reaction between iron and water at room temperature in order to obtain experimental information regarding the fundamental corrosion reaction. The work was conducted in iron vessels, and the water which was used was free of dissolved oxygen and carbon dioxide. This procedure eliminated these gases as factors and also insured the absence of impurities that might be introduced by contact with glass vessels.

It was found that the solution reached a pH value of approximately 8.3 and contained about 0.2 p.p.m. of dissolved iron. The solid product of the reaction is predominantly Fe_3O_4. Previous investigators have reported pH values of the order of 9.0 to 9.6, but it is believed that the use of glass vessels was responsible for higher results than those reported here.

Hypotheses of the fundamental corrosion reaction are discussed as well as the work of other investigators.

The corrosion of iron by water, as experienced in practice, is subject to the influence of substances in solution, notably, oxygen, carbon dioxide, and salts. These factors may be considered as influencing the rate and the type of corrosion, and there is good agreement as to their quantitative effects. The fundamental reaction which occurs when iron is placed in contact with pure water, free of all substances except an inert gas, has received relatively little attention, however, and there are differences of opinion as to the mechanism and the thermodynamic properties of this system.

In 1924, Shipley and McHaffie (**1**)[2] placed iron and steel drillings in water which had been rendered gas-free by boiling. After standing out of contact with air for periods varying from six weeks to over a year, the solutions attained a pH value of 9.4. This pH was assumed to be that which corresponded to a saturated solution of ferrous hydroxide.

Whitman, Russell, and Davis (**2**) in 1925 placed iron powder in deaerated water. The total dissolved iron concentration became 3.75 p.p.m. with a pH value of 9.6. On the assumption that ferrous hydroxide was the product, they calculated that it was 30 per cent ionized.

Murata (**3**) in some similar experiments found a pH value of 9.2. His dissolved iron concentration, however, was 0.41 p.p.m. which was about one-tenth of that found by Whitman, Russell, and

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[1] Chemist, Department of Technical Development and Research, Consolidated Edison Company of New York, Inc., Brooklyn, N. Y.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 1252.

Davis. He concluded that ferrous hydroxide was 100 per cent ionized.

A considerable amount of indirect work, in the nature of thermodynamic speculations, and conductivity, oxidation-reduction potential, and other physico-chemical measurements on iron salts in acid and alkaline solutions, more or less supports the conclusions just given. It is generally believed that ferrous hydroxide is the end product of the iron-water reaction and that the pH value is related to the solubility of ferrous hydroxide.

There is, however, a lack of agreement between the values assigned to the free energy change for the reaction between iron and water (**2,4,5,**), and these values are in turn dependent upon the particular value assigned to the solubility product of ferrous hydroxide according to the relation:

$$K = e^{-\Delta F^\circ/RT}$$

where K = solubility product of $Fe(OH)_2$, and
F° = standard change in free energy

Sweeney (**5**) studied the reaction between iron and water thermodynamically, using recent ΔF° and electrode potential data, with results indicating that the pH and dissolved iron concentration of pure water in contact with iron might not agree with the experimental values quoted above.

If one assumes that no ferrous hydroxide separates from solution, and that the fundamental reaction is the only one which takes place, namely,

$$Fe + 2H^+ \rightarrow Fe^{++} + H_2$$

in which

$$-\Delta F^\circ = 20{,}350 + 1365 \log \frac{(H^+)^2}{(Fe^{++})}$$

then at a pH of 9.6 approximately 3 p.p.m. of dissolved iron will be found. This is lower than that found by Whitman, Russell, and Davis, although they assumed that ferrous hydroxide separated, which, in itself, will produce a lower ferrous iron concentration and pH through the removal of ferrous and hydroxide ions.

Sweeney compared the dissolved iron concentration found experimentally by Baylis (**6**) with that which might be obtained if one utilized the solubility product of ferrous hydroxide found by Britton (**7**). The agreement is quite good, considering that Baylis studied iron in various industrial waters and Britton studied the pH changes which occurred when a soluble ferrous salt in acid solution was titrated with sodium hydroxide.

Using a solubility product constant of $10^{-18.8}$ derived from Britton's data, a saturated solution of ferrous hydroxide was found to have a pH value of 7.8 and a dissolved iron concentration of 0.02 p.p.m. At higher pH values the dissolved iron becomes vanishingly small.

It is true that Britton's constant for ferrous hydroxide is considerably smaller than that of other authors, and the small effect of the ionic strength on K was not considered, but it will be seen later that although it may not be the solubility product constant for pure ferrous hydroxide, it may be an indication that ferrous hydroxide is not the sole product when its production is approached from the acid side of its isoelectric point, as is the case when iron is placed in water.

Baylis (**6**) appears to be the first to express dissatisfaction with the corrosion mechanism which requires the formation of ferrous hydroxide as the only end product of the reaction between iron and pure water, calling attention to the fact that nearly all of the rust formed in the absence of dissolved oxygen is black and quite magnetic and probably an oxide of iron rather than the hydroxide.

An interesting experiment was performed by Schikorr in 1929 (8) which lent support to Baylis' remarks. He placed iron turnings in contact with oxygen-free water in a closed system. A pressure of 18 atmospheres of hydrogen developed, which probably would have been even higher if the experiment had been continued. A black oxide coating was produced on the specimens in 2 hr. The activity for small particles was found to be greater than that for large specimens.

Partridge and Schroeder (9) in an analysis of Schikorr's work explain the difference in activity of specimens of different sizes as being a surface-mass relation, and that a protective oxide layer may be produced on large pieces. There is the additional possibility, however, that the potential differences between the cathodic and anodic points on a plate may be less than those between adjacent particles.

The development of a black oxide coating on iron particles at high temperatures was noticed by Berk and Schroeder (10) who treated fine steel saw cuttings with water for 16 hr. at 250 C.

While the black coating is apparently Fe_3O_4, some X-ray data show that it may contain other substances. Although these data are for conditions other than the direct action of pure water on iron, they seem pertinent: Berl and Van Taack (11), for instance, made an X-ray examination of the product resulting from the corrosion of iron at boiler temperatures and found it to be Fe_3O_4 containing FeO. Cates (12) examined the deposits formed on iron specimens lying at the bottom of a tall column of water. The rate of supply of oxygen to the iron was very low. He obtained corrosion products whose diffraction patterns corresponded to Fe_3O_4 coated with a thin layer of γ-Fe OOH.

Baudisch and Welo (13) offer the following explanation for the formation of Fe_3O_4 in a solution which contains but little oxygen:

> "According to Krause (14), the isoelectric point of Fe $(OH)_3$ when formed by the oxidation of Fe $(OH)_2$ is at pH 5.2. It finds itself in an alkaline medium and immediately assumes an acid character. It then combines with the still unoxidized, strongly basic $Fe(OH)_2$ of isoelectric point, pH 11.5, to form ferrous ferrite according to the reaction:
>
> $$Fe\,(OH)_2^+ + 2\,Fe\,(OH)_3^- \rightarrow FeO \cdot Fe_2O_3 + 4\,H_2O$$
>
> Ferrous ferrite does not oxidize further under these conditions.
>
> "When the rate of oxygen supply is low enough, there is sufficient time for the reaction between Fe $(OH)_2$ and Fe $(OH)_3$ to form $FeO \cdot Fe_2O_3$. At boiling temperature, particularly, the formation of ferrous ferrite is favored because the rate of combination is increased and at the same time the supply of oxygen is diminished. On the other hand, when the supply of oxygen is plentiful, and especially at low temperatures, when the rate of oxidation is high as compared with the rate of combination of Fe $(OH)_2$ and Fe $(OH)_3$, we will have nearly complete oxidation to Fe $(OH)_3$."

Schikorr (8) explained the production of hydrogen and Fe_3O_4 in his experiments in a different manner. He proposed the following reactions as those which occur when iron is in contact with oxygen-free water:

$$3\,Fe \rightarrow 3\,Fe^{++} + 6e \ldots\ldots (1$$

$$2\,Fe^{++} \rightarrow 2\,Fe^{+++} + 2e \ldots\ldots (2$$

$$8\,H_2O \rightarrow 8\,H^+ + 8\,OH^- \ldots (3$$

$$8\,H^+ \rightarrow 4\,H_2 - 8e \ldots\ldots (4$$

$$Fe^{++} + 2\,Fe^{+++} + 8\,OH^- \rightarrow Fe_3O_4 + 4\,H_2O \ldots (5$$

It is interesting that this mechanism suggests that Fe_3O_4 is produced directly from the ions in the absence of oxygen. It would appear also that corrosion would continue indefinitely as long as no protecting film was produced on the metal surface. At the same time, a final pH of 9.0 or greater is doubtful due to the completeness of Eq. 5 to the right.

The formation of ferric ions in Schikorr's equations might be a point of issue, but it is conceivable statistically when one considers the relatively complex electronic structure of iron. Actually, the summation of Schikorr's equations gives the conventional equation for the reaction of iron with steam.

One may use the thermodynamic studies of Murata (4) and calculate that at pH 7.0 the ratio of ferrous to ferric ions is $10^{19.6} \times \sqrt{P_{H_2}}$ where P_{H_2} is the pressure of hydrogen in the system, expressed in atmospheres. According to this, a small amount of ferric ion would exist and enable the solubility product of magnetite to be exceeded. Exact data on the latter is lacking, but it is undoubtedly extremely small.

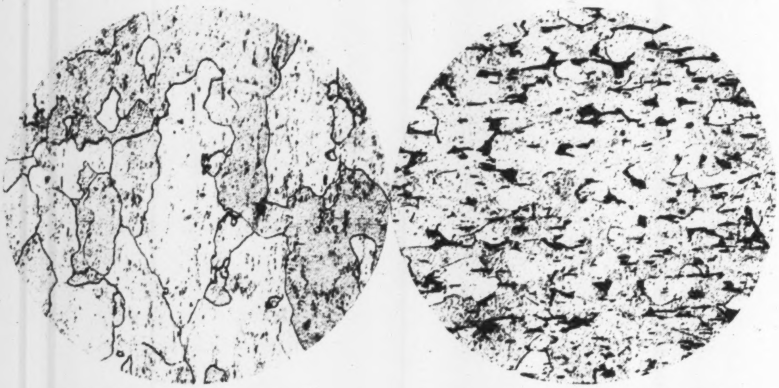
Some work exists which might be taken to indicate that ferrous hydroxide can react with water to produce magnetite. Goldberg in 1915 (15) found that ferrous hydroxide dissociates water to produce hydrogen and oxygen at 200 C. or higher. Schikorr in 1933 (16) found that, in the presence of ferrous ions, ferrous hydroxide liberates hydrogen from aqueous solutions with the production of a dark green magnetic oxide which he believes to contain less than two atoms of divalent iron to one atom of trivalent iron.

These studies, like some of the others which have been mentioned, are important in the literature of the properties of iron, but they are only indirectly applicable to the fundamental corrosion reaction, namely, that which happens when iron is acted upon by water alone. While this reaction has been studied by a few investigators, a set of experiments performed by the authors gave results which are sufficiently different from those which are usually accepted, to justify making them public.

Experimental Conditions:

The desired condition for the experiments was the contact of iron with water which contained no dissolved oxygen or carbon dioxide, in order that the products formed would result only from the reaction of iron and water and not be qualified by the effect of other agents. To achieve this condition, water was prepared which was satisfactorily free of undesirable dissolved gases, and the experiments were conducted in vessels in which a gas other than air was kept above the liquid. At first, commercial tank nitrogen, purified by passing it through chromous sulfate (17, 18) and pyrogallol (19), was used, but as this gas as received contained about 0.2 per cent of oxygen, it was felt that hydrogen would be preferable because of its lower initial oxygen content. Some early experiments were performed in Pyrex flasks, but the results were unsatisfactory because some extraneous factor appeared to have been introduced by the glass. The later experiments were carried out in iron vessels, thereby limiting the system to iron and water. Provision was made in the assembly used for this later work, however, to conduct some simultaneous experiments in glass, and the earlier indications were substantiated.

The iron vessels used were tinned seamless cans, 6 in. high and 5 in. in diameter. They were made of stock containing 0.07 to 0.10 per cent carbon and about 0.3 per cent manganese (Fig. 1 (*a*)). The tin was completely removed with hot hydrochloric acid. While still wet, the cans were quickly and thoroughly washed with hot water (70 C.) and then wiped dry with clean cloths. They were then filled with hot U.S.P. 95 per cent ethyl alcohol, drained, and again wiped dry. Cans of this type made convenient vessels, but it was found necessary to use seamless cans as the wash water of those with the ordinary folded joints showed small quantities of chloride ion even after many successive washings, presumably because of occlusion of the acid in the capillary spaces at the joint.



(*a*) Sheet steel used in container. (*b*) $\frac{1}{4}$-in. bar stock steel specimen.

FIG. 1.—Photomicrographs of Materials Used for Containers and Specimens (× 100). Etched in Nital.

The cleaned cans were fitted into two steel nipples, diametrically opposed, one being placed about 1 in. from the top of the can and the other about 1 in. from the bottom. The upper nipple served to supply the vapor space with hydrogen and the lower one was used for drawing samples.

The glass vessels were 800 ml. Pyrex Kjeldahl flasks. Before use they were cleaned with hot potassium dichromate - sulfuric acid mixture, washed with water, then steamed out for 30 min. and finally filled with conductivity water and stored for about one week before use.

The quartz flask was the same type as the glass flasks, and was prepared in the same manner.

Iron powder was used as the reactant in some of the early experiments. Several grades of powder were studied, some of which had been prepared by reducing iron oxide while others were iron filings reported to be of U.S.P. grade. It was found that oxygen-saturated aqueous extracts of these powders were alkaline to phenolphthalein and upon evaporating to dryness yielded isotropic and anisotropic crystals, neither type being identified as iron compounds. It was decided that the desired experimental conditions could not be obtained if the iron reactant introduced a foreign substance into the system, so the use of iron powder was abandoned.

The results reported here were obtained with iron (steel) bars prepared from 12-cm. lengths of $\frac{1}{4}$-in. bar stock. Figure 1 (*b*) shows their microstructure. They were prepared for use by cleaning in 10 per cent sulfuric acid at 50 C. followed by a rapid stream of water at 70 C. Then they were immersed in hot 95 per cent ethyl alcohol for several minutes, and quickly dried. No contaminants from the pickling acid remained after this treatment. The bars were stored in a desiccator until used. When specimens were used repeatedly, instead of treating them with acid they were rolled in an Abbe mill lined with ingot sheet iron for several hours. They were then washed with hot water and alcohol as above. This treatment prepared the specimens for the succeeding experiment.

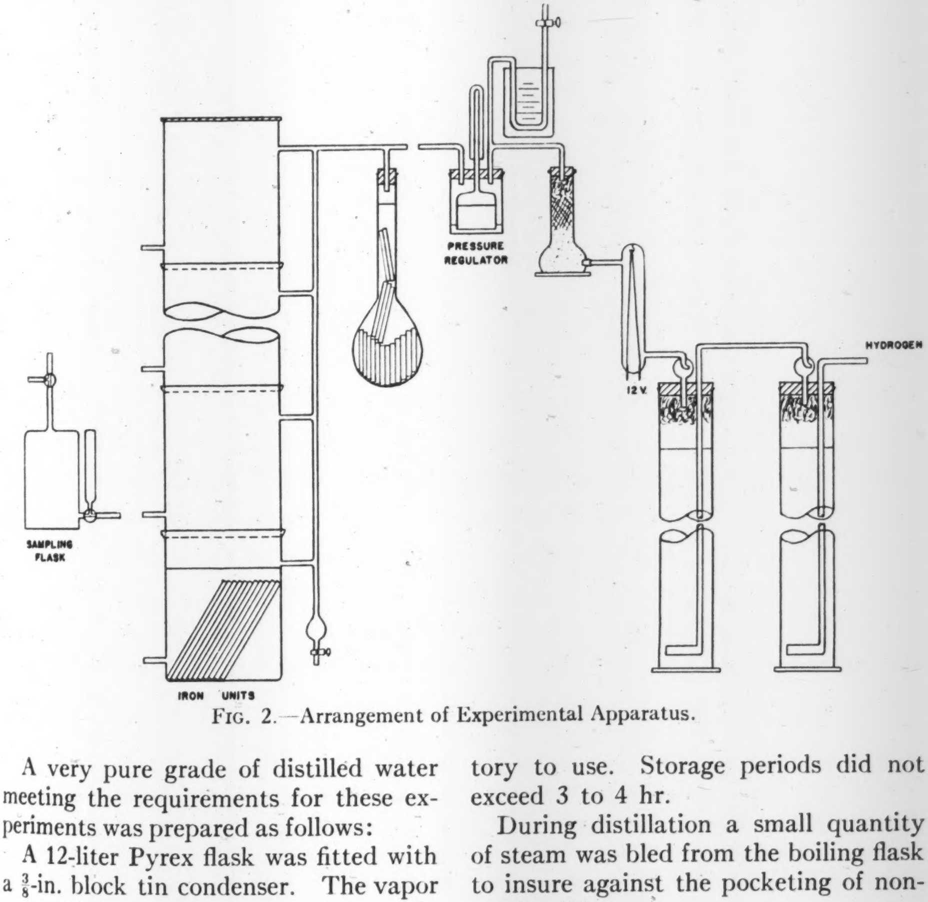


Fig. 2.—Arrangement of Experimental Apparatus.

A very pure grade of distilled water meeting the requirements for these experiments was prepared as follows:

A 12-liter Pyrex flask was fitted with a $\frac{3}{8}$-in. block tin condenser. The vapor end of the condenser was elaborately baffled to prevent carry over. Pieces of porcelain were placed on the bottom of the flask to prevent bumping.

The flask was one-half filled with ordinary distilled water made 0.025 molar with orthophosphoric acid as recommended by Ellis and Kiehl (**20**). During boiling, a continuous stream of purified nitrogen was passed through the water. Several liters of water were distilled and discarded before the distillate was used to fill the corrosion vessels. The condensate was collected in a 2-liter Pyrex aspirator bottle under an atmosphere of nitrogen. This flask served as a temporary reservoir preparatory to use. Storage periods did not exceed 3 to 4 hr.

During distillation a small quantity of steam was bled from the boiling flask to insure against the pocketing of noncondensible gas.

The condensate consistently gave a pH value of 6.95. Tests for tin, phosphoric acid, and dissolved oxygen were made and found to be negative.

The hydrogen used to insure the absence of oxygen and carbon dioxide was prepared by purifying tank hydrogen by means of the train shown in Fig. 2. The gas passed first through two towers, 18 in. in height, the first of which was three-fourths filled with a pyrogallol solution prepared according to Wolf and Krause (19), while the second was about one-fourth full of syrupy potassium hydroxide. Jena sintered glass gas distributors No. 33cG4 were used to distribute the gas entering these towers. The hydrogen then passed through a Jena glass chamber containing 10 in. of No. 22 platinum wire which was heated to about 1000 C. The last chamber contained a layer of ascarite on top of which was a layer of calcium chloride separated from the ascarite by a thin wad of glass wool. The top of the tube was firmly padded with absorbent cotton to prevent powdery calcium chloride from being carried over by the gas.

At the start of an experiment, the units were loaded with as many rods as they could hold, thereby making the iron-water ratio as high as possible. In order to save space, and for convenience in manipulation, the cans were stacked one upon another as shown in Fig. 2. Leaks were prevented by sealing the junctions between adjacent cans with a mixture of paraffin and beeswax. This was also used to seal the cover on the topmost unit.

Pyrex or quartz flasks were attached to the system as shown in the figure.

The air in the vessels was then displaced by hydrogen. This was done by opening the sampling outlets of the cans and passing a rapid stream of hydrogen for several hours. The vitreous units attached to the apparatus were freed of air and filled with gas-free distilled water before attaching them to the system.

Water was then added through the sampling nipples until it overflowed through the hydrogen inlet connections. During this time a lively rate of flow of hydrogen was maintained. The water which overflowed was drained out through the cock at the bottom of the hydrogen manifold.

The pressure in the system was kept at about 2 in. of water by adjusting the height of the bell in the pressure regulator. Except when checking the pressure, the valve to the manometer was kept closed.

No temperature control was used, but, fortuitously, the room temperature was close to 25 C. during the experimental period.

All the units were vigorously agitated at frequent intervals.

At the end of selected periods of time the contents of the vessels were withdrawn and analyzed.

pH Determination:

The sampling flask shown in Fig. 2 was used for transferring the liquid from a reaction vessel to the electrode assembly. It consisted of a Pyrex vessel fitted with two 3-way cocks and an external tube of about 15-ml. capacity. The upper tube was attached to a hydrogen supply and by the proper adjustment of the cocks the flask could be either completely freed of air, or, during sampling through the lower tube, a hydrogen atmosphere could be maintained over the liquid.

Before use, this vessel was aged for a few weeks with conductivity water, and it was kept filled with such water during the period between pH determinations. Several experiments were made in order to determine whether, during the short time the samples were in contact with the vessel, the pH value of the sample was altered. No change was found.

The first step in the determination of the pH value was to run a colorimetric determination on a small sample collected in the vertical side tube of the flask. The three-way cock was then manipulated to allow a 350-ml. sample to flow into the body of the flask, whence it was allowed to flow to the electrode at the rate of about 30 ml. per min. An atmosphere of hydrogen was maintained in contact with the liquid at all times.

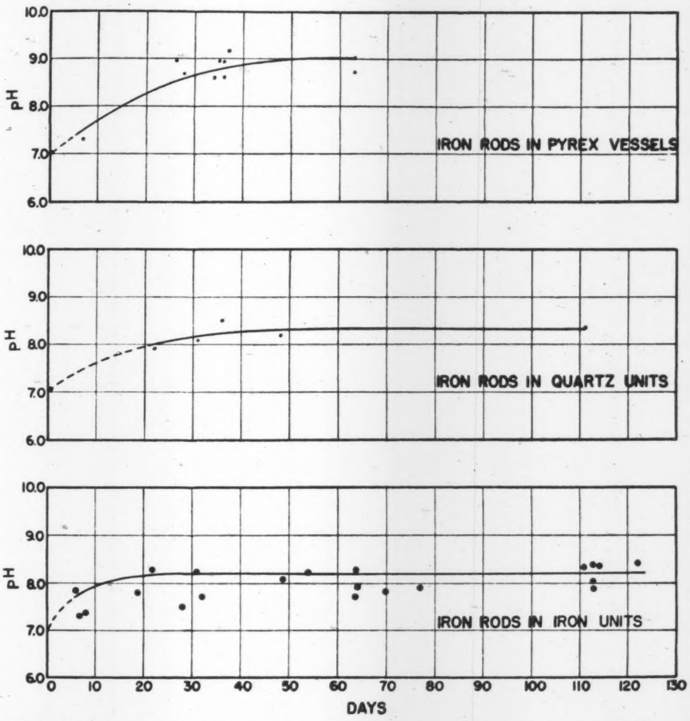


FIG. 3.—The pH Changes Resulting from the Reaction Between Iron and Pure Water.

A Beckman No. 190 F R glass electrode assembly, for use on free flowing aqueous solutions up to a pH of 9.5, was employed. The internal referent was quinhydrone-saturated, 0.1 molar hydrochloric acid. The calomel half-cell was of the saturated type. The liquid junction was made in a capillary connection to the flow chamber, thereby avoiding diffusion of potassium chloride into the sample. The electrode was repeatedly checked against buffers between pH 4 and 9.

The method used to determine the e.m.f. of the glass electrode was that in which the glass electrode potential is opposed by an externally connected potentiometer, and the unbalanced voltage applied to the control grid of a General Electric Pliotron F.P. 54 tube. The circuit is designed so that the plate filament resistance forms one arm of a Wheatstone bridge. The plate load resistance is approximately the same as the plate resistance of the tube and, consequently, the circuit sensitivity is a maximum (21).

A Leeds & Northrup No. 2420A galvanometer was used to indicate a balanced bridge circuit. The over-all sensitivity of the apparatus was 0.03 pH units.

Iron Determination:

Iron was determined colorimetrically on a 50-ml. sample collected out of contact with air through a filtering device consisting of a 20-cm. length of 4-mm. Pyrex tubing, part of which was plugged with purified cotton, followed by a Jena No. 15aG4 sintered glass filter tube. This filtering precaution was necessary in order to avoid the introduction of minute particles of corrosion product into the sample and to insure that the subsequent determination represented the iron which was in solution.

A modification of the method of Saywell and Cunningham was used (22). In this method an acidified sample is treated with hydroxylamine hydrochloride and ortho-phenanthroline, then titrated with ammonium hydroxide using congo red paper as an indicator. The resulting color is matched against that of iron standards prepared in the same way. It is specific for ferrous ion, the presence of hydroxylamine insuring that all of the iron is in that form. By omitting this reagent a determination of ferrous iron can be made, and the ferric iron can then be determined from the difference between this result and that of the total iron determined on another sample.

Many of the results were checked by the thiocyanate method described by Rakestraw, Mahncke, and Beach (23). In this method the color of the hexathiocyanato-ferriate complex is stabilized with ethylene glycol monobutyl ether.

Results:

Iron Rods in Iron Vessels.—Figure 3 shows the pH values attained. Each point represents a different experiment, that is, the result obtained when one of the several units was examined at the end of a desired time period. None of the results is a successive determination on the same unit. The pH value of the water from the container opened after 20 days is about 8.2, while that opened after 120 days is 8.2, indicating that the final pH value is approximately 8.2 under the conditions of this experiment and is reached soon after the start of an experiment. The curve has been drawn to favor the higher pH values because it is thought that they are more typical than the lower ones and that the latter represent the influence of some unknown variable which resulted in a comparatively small effect upon the final value.

It might be argued that the higher values are themselves too low and that, if the vessels had been allowed to stand, the pH values would have risen. It does not seem likely, however, when one considers that, out of all the experiments performed, no value greater than pH 8.35 was found. It is concluded, therefore, that a pH value of the order of 9.4 or 9.6 would not be obtained under the conditions of these experiments.

The solutions contained 0.3 ± 0.1 p.p.m. of iron, which, by the ortho-phenanthroline method was established as being in the ferrous form. As the dissolved iron did not follow the pH value proportionately, there is some likelihood that some of it was in the colloidal condition.

When samples of the liquid from some of the vessels were saturated with oxygen the pH fell to 6.6 ± 0.1 and the liquid became slightly turbid. This indicated the absence of contributing factors other than ferrous iron to the increase in pH value.

The walls of the iron units appeared metal-clean immediately after opening them. A thin black skin was found on the metal above the water line. The rods were coated with an almost imperceptible black stain except for the ends where a slightly heavier deposit was found.

A black powder of high magnetic

susceptibility lay on the bottom of every unit. The particles comprising this powder were unresolvable at 900 diameters. The X-ray pattern, shown in Fig. 4, is that of Fe_3O_4. The amount of this loose powder increased with the length of time a unit was in service.

Iron Rods in Quartz Vessels.—The pH value appeared to approach 8.2 as a limit with an average deviation of about 0.15 pH units. The dissolved iron concentration was less than 0.05 p.p.m.

The evolution of hydrogen from the rods was noticeable 24 hr. after the start of an experiment. Perceptible darkening of the rods was observed in 48 hr., and in this case also, the ends appeared to be coated more heavily than the rest. A black oxide, identical in appearance with that found in the iron units, was found on the bottom of the flask.

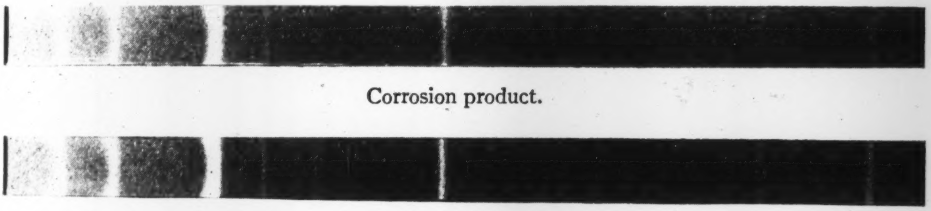
Iron Rods in Pyrex Vessels.—The pH value of the water in the Pyrex flasks rose to 9.0 with no indication that this was the maximum. (A few experiments conducted with a softer glass resulted in a pH value of 9.5 in about 25 days.) The dissolved iron concentration was usually less than 0.05 p.p.m. In a few cases it was between 0.05 and 0.1 p.p.m. Hydrogen evolution and the characteristics of the oxide product were about the same as observed in the quartz vessels with, however, some indication that more oxide was produced in a quartz vessel in the same length of time. Certain observed facts in connection with these experiments, however, must be noted:

1. When oxygen was passed through the liquid at the end of an experiment, the pH value dropped but about 0.2 pH units, instead of to below 7.0 as was the case with the water from the iron containers. This suggests that the hydroxide ion concentration was governed by something other than ferrous iron.

2. A small quantity of extremely thin, flaky material of a brownish transparency was found in the bottom of the flask. A microchemical test indicated that it contained iron and silicon.

3. When air-free distilled water, but with no iron rods, was stored in Pyrex flasks for several weeks, the pH value did not increase above 7.3, indicating that a simple extraction of the glass did not occur.

The only conclusion possible, therefore, is that, in these experiments at least, a chain of reactions is started by the minute solubility of the glass constituents with the result that end products different from those of the fundamental corrosion reaction are found. This observation suggests that the conclusions drawn from previous studies of this reaction, in which glass vessels were used, may have to be modified.



Corrosion product.

Standard magnetite.

FIG. 4.—X-ray Diffraction Pattern of Corrosion Product.

Discussion and Conclusions:

The reaction which occurs when iron is in contact with distilled water free of oxygen and carbon dioxide may be considered as the fundamental reaction of the corrosion of iron. These studies have indicated that the solid end product of this reaction is the magnetic oxide Fe_3O_4. The final pH value, when no glass is in contact with the liquid, is of the order of 8.2. The presence of glass apparently alters the fundamental reaction, and if one agrees with Morey (24) that glass and water constitute a liquid-liquid system with probable miscibility in all proportions, then it seems possible that some reaction takes place between dissolved iron and glass, although the amount of dissolved glass may be extremely small.

The equations quoted from Schikorr's work in 1929 may be said to illustrate the process by which Fe_3O_4 is produced, but it is desirable to offer a more dynamic explanation in view of the well-established fact that water is decomposed by ferrous hydroxide.

Baudisch and Welo (13) believe it is necessary to have oxygen present in order for this reaction to occur. However, Schikorr has reported (16) that it can take place in air-free water and at a rate inversely proportional to the pH.

One may then conceive of an oxidation process in which the initially formed ferrous hydroxide decomposes the water to form magnetite as the final solid product. The production of the ferrous hydroxide is approached from a neutral solution which, according to Schikorr's results, should enhance the decomposition phenomenon.

The presence of dissolved iron may be looked upon as an intermediate stage of a chain of coexistent reactions, as

$$Fe \rightarrow Fe^{++} \rightarrow FeO \cdot H_2O \rightarrow Fe_3O_4$$

Lack of information about the state of the dissolved iron (that is, colloidal or poorly ionized) the disagreement in the literature as to the solubility product of ferrous hydroxide, and the inability to determine which of the above reactions is the controlling one, have made the authors purposely avoid attempting to correlate the dissolved iron and pH values obtained.

Acknowledgments:

The authors wish to acknowledge the advice and assistance rendered by Mr. A. R. Mumford of the Consolidated Edison Co.; also the advice on the vacuum tube potentiometer circuit given by Mr. Fred Rosebury of the College of Physicians and Surgeons of Columbia University.

Mr. F. G. Foote of Cooper Union made the diffraction analysis of the corrosion product through the kindness of Dr. Eric Jette of Columbia University in making the X-ray apparatus available.

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DISCUSSION

Mr. U. R. Evans[1] (*presented in written form*).—The paper by Messrs. Corey and Finnegan has greatly clarified our knowledge of the reaction of iron with water. The fact that the authors have worked mainly in iron vessels, and the important differences between the results obtained in these experiments and those in which the water was brought into contact with glass, gives a special importance to the research. This feature of the matter is of special interest to me, since in the Cambridge laboratory we have used—for quite different purposes—procedures in which water is brought into contact with metal, in some cases without any contact with glass, and in others with only a brief contact during the setting up of the experiment. I have, for instance, condensed water in drops from supersaturated air directly on the metal,[2] and my colleague, Mr. Mears,[3] has ruled iron sheets with waxed lines, so that water would stand on the surface in square drops—a method which we have found useful for statistical studies. Neither of these procedures would have been entirely suitable for the research under discussion, and the use of iron bottles was probably the best way out of the difficulty, although it has probably involved the employment of iron under stress and it is doubtful whether it could be adapted to the study of pure iron; moreover the adoption of detinned tin plate as a material involves questions as to whether traces of tin salts—which possess inhibitive properties—may not remain on the metal, even after the wash-water ceases to contain tin. None of these factors appears to invalidate the authors' conclusions, but they should receive careful consideration from anyone who proposes to employ the iron bottle technique for other purposes.

Some years ago, two quite independent explanations were available to explain the slow attack of water on iron in the absence of oxygen, acids, or salts. According to the first, the liquid next the metal became supersaturated with ferrous hydroxide, which separated out as a protective film, isolating the metal from the water. According to the second, the reaction led to an increase in the Fe^{++} ion concentration and a decrease in the H^+ ion concentration, until the equilibrium

$$Fe + 2H^+ \leftrightarrows Fe^{++} + H_2$$

was set up, and the reaction ceased, even though no solid film was present on the metal. The distinction was fundamental, and not without practical importance, since if the first mechanism were operative, then stirring of a certain character might cause the first nuclei of ferrous hydroxide to be formed at a distance from the metal, so that the stifling would not take place, whereas according to the second mechanism, equilibrium must ultimately be arrived at, in a vessel of finite size, however violent the stirring.

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[1] Assistant Director of Research (Metallurgy), Cambridge University, England.

[2] U. R. Evans, "The Porosity of Metals, Part IV: The Influence of Acids in Passivity and Corrosion," *Journal*, Chemical Soc. (British), p. 478 (especially p. 486) (1930).

[3] U. R. Evans and R. B. Mears, "The Velocity of Corrosion from the Electrochemical Standpoint: Part III," *Proceedings*, Royal Soc. (London), A, Vol. 146, p. 153 (especially p. 164) (1934).

R. B. Mears and U. R. Evans, "The 'Probability' of Corrosion," *Transactions*, Faraday Soc., Vol. 31, p. 527 (especially p. 530) (1935).

The situation has become radically altered since Schikorr showed that ferrous hydroxide could itself decompose water, yielding magnetite and hydrogen. But it still remains important to ascertain whether a *solid* film of ferrous hydroxide is transformed into a magnetite film, which presumably would then retain at least some protective action, or whether *dissolved* ferrous hydroxide yields magnetite (which would then presumably be loose, nonadherent and nonprotective). Under the conditions prevailing in the research under discussion, the magnetite was found on the bottom of the bottles as a loose black powder, the walls themselves being clean, except above the water line. This seems to support the second mechanism, suggesting that no solid ferrous hydroxide was formed, and that the solid magnetite arose from dissolved ferrous hydroxide.

It is clear that, if magnetite is formed as a loose product, the attack on the iron can continue indefinitely, since the transformation of ferrous hydroxide to magnetite will prevent the equilibrium

$$Fe + 2H^+ \leftrightharpoons Fe^{++} + H_2$$

being reached. But the attack on the iron is evidently exceedingly slow, unless oxygen is present, which will convert ferrous hydroxide to hydrated ferric oxide (rust), thus upsetting the equilibrium and permitting the attack to continue. Even here there is a limit to the rate of attack. If only a small amount of oxygen is present in the gas atmosphere, and the liquid is stagnant, ferrous hydroxide must diffuse to the point where oxygen is present in excess and, since the equilibrium concentration of ferrous hydroxide is small, the diffusion will necessarily be slow, and consequently the rate of attack must be slow also. By increasing the oxygen concentration in the gas phase, or by stirring the liquid, the rate of transformation of ferrous hydroxide to hydrated ferric oxide is clearly increased, but there is an increased probability of producing the hydrated ferric oxide as an adherent, protective film, which will stifle further attack, (in the most favorable circumstances, before it reaches visible thickness). In the statistical work of Mears and myself, mentioned above, it was found that, when drops of distilled water were placed on iron in oxygen-nitrogen mixtures of different composition, the proportion of drops causing rust steadily *diminished* as the oxygen-concentration increased, although the velocity of attack increased in those drops where there was any attack at all.

In practice, rapid rusting requires the presence of acid or salts. The rapid rusting produced by rain or condensed water in industrial atmospheres full of sulfur oxides (derived from coal smoke) is probably due to the fact that ferrous sulfate can be formed in quantities not limited by any equilibrium, and is then converted by oxidation to a mixture of ferric sulfate and hydrated ferric oxide, which is thrown down (at least partly) out of physical contact with the metal, so that the layer of rust, although adhering at places, does not form a complete protective film. The rusting caused by salt water is an electrochemical phenomenon which leads to ferrous chloride and sodium hydroxide at the anodic and cathodic spots, respectively, and these will interact, with a further quantity of oxygen, to give hydrated ferric oxide (rust), which here again is formed at a perceptible distance from the seat of anodic corrosion and thus does not stifle attack. In such cases, the electric currents flowing over corroding metal have actually been detected, and, in cases where they can be measured, they are sufficiently strong to account for the whole, or at least the greater part, of the attack.[4] The special danger of electrochemical corrosion is that, by spatially removing the anodic and cathodic products, it produces the secondary corrosion product (that is, rust) at a place where it will not stifle attack.

MR. R. B. MEARS[5] (*presented in written form*).—The authors have done an important service in demonstrating that the solid end product in the corrosion of iron in distilled water free of oxygen and carbon dioxide is Fe_3O_4. Their use of iron vessels to hold the corrosion specimens in one set of experiments in order to avoid any special effect which might be caused by the nature of a vessel of some other material was particularly ingenious. However, since they have now apparently demonstrated that quartz vessels cause no specific effect of their own, but yield results similar to those obtained with iron vessels, it would appear desirable to extend the work to include a study of the corrosion of very pure iron. The authors have taken pains to purify the gases and liquids employed in their studies. If, in addition, pure iron were also used, results of great theoretical importance would be obtained. It would also be of interest if the authors would give some indication of the rate of attack of the rod specimens under these anaerobic conditions.

The authors state that: "The walls of the iron units appeared metal-clean immediately after opening them." Since it is also stated that the rods were coated with a faint black stain, how do the authors account for the fact that the iron vessels were not so coated?

MR. CARL W. BORGMANN[6] (*presented in written form*).—The results reported by Corey and Finnegan are of considerable theoretical importance and the authors are to be congratulated on their contribution. The only purpose of the present discussion is an attempt to forestall those who may point to this paper as a reason to cast all previous corrosion work to the winds—as being conducted under questionable experimental conditions whenever glass containing vessels were used. I doubt that the authors will be among this group.

There is one very important and fundamental difference between these tests and the usual laboratory corrosion tests in neutral solutions, namely, that the corrosion mechanism in one case is that of hydrogen evolution, whereas in the other, oxygen depolarization accounts for the major proportion of corrosion. It would, consequently, be of considerable interest to determine whether glass vessels have an influence on both the amount and character of corrosion in neutral solutions and under conditions of the presence of oxygen. One can suggest that there is one particular field where an appreciable influence may be found. If the experimental system of metal and environment is such that small differences in either will determine whether or not breakdown will occur, we can expect that the presence of a glass vessel may cause major changes in the attack. Such a system could be exemplified by a sodium chloride - sodium chromate solution and steel. At critical concentrations, exceedingly trivial factors can play major roles in determining whether the metal shall be unattacked or be pitted. Under such conditions, and other comparable ones, the presence of glass may be of importance. However, the writer feels that such a factor will prove to be of little importance under the vast majority of experimental conditions.

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R. S. Thornhill and U. R. Evans, "The Electrochemistry of the Rusting Process Along a Scratch-Line," *Journal*, Chemical Soc. (British), p. 614 (1938).

[5] Metallurgical Division, Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pa.

[6] Head of Department of Chemical Engineering, University of Colorado, Boulder, Colo.

MR. J. C. WARNER[7] (*presented in written form*).—We wish to point out that the results obtained experimentally by the authors are in agreement with the latest thermodynamic data.[8] According to these data, as will be shown below, the reaction (1) between iron and pure oxygen-free water leading to the formation of the ferroferric oxide (magnetite) and hydrogen seems definitely to be more spontaneous than the reaction (2) leading to the formation of ferrous hydroxide and hydrogen. The data on ferric compounds are not very certain and it is difficult to decide whether the reaction (3) between iron and oxygen-free water leading to the production of hydrogen and a solid phase in which *all* of the iron is in the ferric state is slightly spontaneous or slightly nonspontaneous. At any rate, it seems certain that the latter reaction is less spontaneous than either of the first two and that the most spontaneous reaction between iron and oxygen-free pure water is the one in which ferroferric oxide and hydrogen are the products.

$$3\mathrm{Fe(s)} + 4\mathrm{H_2O(1)} = \mathrm{Fe_3O_4(s)} + 4\mathrm{H_2(g)} \ldots\ldots (1)$$

At 25 C., $\Delta F^\circ = -15{,}060$ cal.;
Equilibrium pressure of hydrogen gas = 575 atmospheres

$$\mathrm{Fe(s)} + 2\mathrm{H_2O(1)} = \mathrm{Fe(OH)_2(s)} + \mathrm{H_2(g)} \ldots\ldots (2)$$

At 25 C., $\Delta F^\circ = -2280$ cal.;
Equilibrium pressure of hydrogen gas = 46 atmospheres

$$2\mathrm{Fe(s)} + (3 - 6)\mathrm{H_2O} \rightarrow \mathrm{Fe_2O_3}\cdot(\mathrm{O} - 3\mathrm{H_2O}) + 3\mathrm{H_2} \ldots\ldots (3)$$

At 25 C., ΔF° may vary from −6000 to +7500 cal., depending upon the data selected and the extent of hydration of the solid product; equilibrium pressure of hydrogen gas would lie in the range 29.0 to 0.015 atmospheres.

Solid ferrous hydroxide should spontaneously yield ferroferric oxide, water and hydrogen:

$$3\mathrm{Fe(OH)_2(s)} \rightarrow \mathrm{Fe_3O_4(s)} + 2\mathrm{H_2O(1)} + \mathrm{H_2(g)} \ldots\ldots (4)$$

Thus, in a solution saturated with ferrous hydroxide, one would expect liberation of hydrogen and the accompanying formation of magnetic oxide. The remark in the paper attributed to Goldberg that "ferrous hydroxide dissociates water to produce hydrogen and oxygen" is obviously in error—only hydrogen would be produced.

Since the conversion of ferrous hydroxide into ferroferric oxide is spontaneous, one could expect to obtain saturated solutions of ferrous hydroxide in the experiments performed by the authors only if Eq. 4 above is slow compared to Eq. 2. It seems likely that this is not the case because the solid phase saturating their solutions appears to be almost entirely the magnetic oxide. If their solutions were less than saturated with respect to ferrous hydroxide, one would expect a lower pH than that calculated from the solubility product of $\mathrm{Fe(OH)_2}$ (solubility product = 1.65×10^{-15}, pH = 9.17). The authors' value of pH = 8.2 should be that of a solution saturated with $\mathrm{Fe_3O_4}$. Inasmuch as they obtained practically identical results in quartz as in iron vessels, it would be interesting to determine the pH of oxygen-free water (in quartz) saturated with Fe_3O_4 without iron being present.

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[7] Professor of Chemistry, Carnegie Institute of Technology, Pittsburgh, Pa.

[8] The calculations upon which this discussion is based make use of data taken from:

F. R. Bichowsky and F. D. Rossini, "Thermochemistry of Chemical Substances," Reinhold Publishing Corp., New York City (1936).

W. M. Latimer, "Oxidation Potentials," Prentice-Hall, New York City (1938).

K. K. Kelly, "A Revision of the Entropies of Inorganic Substances," *Bulletin 394*, U. S. Bureau of Mines (1936).

J. Chipman and D. W. Murphy, *Industrial and Engineering Chemistry*, Vol. 25, p. 319 (1933).

Calculations similar to those used as a basis for this discussion are well illustrated by many examples in the paper by D. S. McKinney on "The Calculation of Equilibria in Dilute Water Solution."[9]

MR. F. N. SPELLER.[10]—The experimental data given in this paper confirm the formation of Fe_3O_4 as a solid end product of corrosion of iron in water. This black oxide has been found in closed hot water systems and steam boilers where the dissolved oxygen was very low. The determination of the final pH (8.2) of the water not in contact with glass, and the discussion of these reactions, are important contributions to fundamental knowledge of corrosion mechanism. The final pH of water in contact with iron will probably vary to a certain extent with the temperature and other variables. It is interesting to note that about six times as much iron in solution was found in quartz vessels as in iron vessels, both solutions being at the same pH (8.2). The greater number of electrolytic contact cells in the iron vessel may be a factor. The authors have paved the way for further research work necessary to a better understanding of the details of these reactions.

MR. H. H. UHLIG.[11]—I agree with Mr. Speller that more work is necessary on this equation so fundamental in the study of corrosion. I believe that Messrs. Corey and Finnegan have pointed out something of considerable interest. More work is necessary, however, before one could in any general sense state that Fe_3O_4 is the corrosion product of iron reacting with water. For example, if iron powder is added to deaerated distilled water and this is allowed to stand for some hours, the resulting alkaline solution tests positive for ferrous ions, but not for ferric ions.

The effect of the container on the nature of the corrosion product finds a suggestion of explanation in the work of Kohlschütter.[12] He found that silver oxide reduced by hydrogen in aqueous media assumed different sized particles and colored colloidal sols depending on the container he used. If quartz were used, the color of the colloidal silver was yellow-brown, but if Jena glass were used, the sol was colored red to blue. Ferrous hydroxide being colloidal, might it not be possible that analogously the particle size of the corrosion product of iron varies with the nature of the container? The smaller the particle size of ferrous hydroxide, the greater would be its solubility in water, and hence the lower would be the resulting hydrogen ion concentration.

MESSRS. RICHARD C. COREY[13] AND THOMAS J. FINNEGAN[13] (*authors' closure by letter*).—Mr. J. C. Warner has submitted thermodynamic evidence which corroborates the experimental results. The authors believe, however, that the complex and not entirely understood nature of ferrous hydroxide (ferrous oxide hydrate) makes it questionable to draw definite conclusions with respect to the behavior of the system which has been studied, on the basis of available thermodynamic data.

The free energy relations compiled by Mr. Warner indicate that solid ferrous hydroxide will most probably decompose into magnetite and hydrogen. It is pertinent, however, to consider the rate at which this reaction occurs, a factor that is not evaluated by thermodynamics.

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[9] See p. 1191.

[10] Advisory Engineer, National Tube Co., Pittsburgh, Pa.

[11] Research Associate, Massachusetts Institute of Technology, Cambridge, Mass.

[12] V. Kohlschütter, "Über Reduction von Silberoxyd Durch Wasserstoff und Kolloides Silber," *Zeitschrift für Elektrochemie*, Vol. 14, p. 49 (1908).

[13] Chemist, Department of Technical Development and Research, Consolidated Edison Company of New York, Inc., Brooklyn, N. Y.

For example, it is possible to preserve a saturated solution of ferrous hydroxide, out of contact with oxygen and iron for years without undergoing appreciable decomposition. Herein lies an argument to support the contention that pure water in contact with iron will acquire a pH of 9.0 or greater when equilibrium has been established between dissolved and solid ferrous hydroxide. Concomitantly, the thermodynamic conclusion that decomposition into magnetite and hydrogen occurs is supported, for if given sufficient time the reaction will be complete.

It appears therefore that the reaction mechanism should be considered with particular reference to the role of the hydrogen ion concentration and the chemical nature of ferrous hydroxide. Reference already has been made in the paper to the relation of pH to the reaction rate. Unfortunately there is a dearth of information in the literature dealing with the properties of pure ferrous hydroxide based upon experiments with the pure compound; thus its solubility product, isoelectric point, and solubility in pure water have by no means been established definitely. With these questions in mind the authors are prone to regard data obtained by indirect methods with considerable reserve.

It has been reported in the literature that the water molecule in the $FeO \cdot H_2O$ lattice is quite active.[14] Thus, freshly prepared ferrous hydroxide readily reduces alkali nitrates to nitrites and, if oxidized with molecular oxygen, it yields α-Fe_2O_3. Aged ferrous hydroxide, however, will not reduce nitrates and yields α-$Fe_2O_3 \cdot H_2O$ when oxidized.[15] These phenomena appear to indicate that the water molecule undergoes a lattice transformation in time with a change in free energy of the compound that has not been generally recognized.

Further, the relation of pH to the rate of decomposition of ferrous hydroxide indicates that hydroxyl ion stabilizes the ferrous hydroxide lattice.

These points have been discussed, not as an indictment of thermodynamic treatment, but to emphasize the need for considerably more information on the chemical and physicochemical properties of pure ferrous hydroxide, especially in relation to the iron-pure water system.

On the basis of thermodynamic argument, Mr. Warner believes that it is not possible for oxygen to be produced by the decomposition of ferrous hydroxide. It may be of interest to note that recently published work by Churchill[16] shows that hydrogen peroxide is produced during the corrosion of aluminum, magnesium, zinc, and tin. No peroxide has been detected during the corrosion of iron, but it is possible that a peroxide may be formed, but it is of so ephemeral a nature as to elude the analytical technique used.

Certainly this is not substantial evidence that iron corroding in the absence of oxygen will produce oxygen spontaneously as the result of the decomposition of a peroxide, but again, considering the complex nature of iron oxides and hydrates, it is not likely that the fundamental corrosion mechanism is amenable to a simple explanation.

The possible effect of residual tin salts in the iron corrosion units, mentioned by Mr. Evans, was thoroughly investigated as follows: Tin determinations were made on the solution from several of the units at the conclusion of the experiment. In no case was tin found. Several of the experimental runs were conducted in a low-carbon steel extruded cylinder cut from a compressed gas bottle. Prior to use the inside was machined free of surface defects and finally cleaned with pure solvents. The pH and dissolved iron results agreed perfectly with those obtained by the other technique. These studies were considered to be sufficiently conclusive that there were no interfering factors introduced by the use of detinned vessels.

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[14] G. F. Hüttig and H. Möldner, *Zeitschrift für anorganische und allgemeine Chemie,* Vol. 196, p. 129 (1931).

[15] O. Baudisch and L. Welo, "Magnetic and X-ray Studies on the Ageing of Ferrous Oxide Hydrate," *Naturwissenschaften,* Vol. 21, p. 659 (1933).

[16] J. R. Churchill, "The Formation of Hydrogen Peroxide During Corrosion Reactions," *Preprint No. 76-7,* Electrochemical Soc. (1939).

In reply to Mr. Mear's query with respect to the appearance of the walls of the vessels at the conclusion of the experiment, it was found that the apparent difference was one of degree rather than kind. When the walls of the vessels were quickly wiped with a white cloth immediately after opening, a black smudge indicated that an oxide was present but to a much smaller extent than on the rods. This difference in amount of oxide is possibly due to the rods being more anodic than the vessels with which they were in contact as the result of the greater microstructural heterogeneity of the former. Consequently the "plating out" of hydrogen on the cathodic walls caused the Fe_3O_4 produced *in situ* by local action to be less adherent due to the scrubbing action of the hydrogen.

The authors have investigated the result of adding five different grades of commercially available iron powder to pure water. All, excepting Kahlbaum's research grade, caused the water to become alkaline to phenolphthalein within a few minutes. The Kahlbaum powder did not cause any change in pH in 24 hr. The difference in behavior was traced to the presence of alkaline impurities in the powders. The authors submit these results to Mr. Uhlig as an explanation for the observations which he made with iron powder.

The work of Kohlschütter mentioned by Mr. Uhlig is of considerable interest. Its application to this work, however, would require two presumptions: first, that ferrous hydroxide is colloidal under the experimental conditions, and second, that ferrous hydroxide is present at any time as a solid phase. It would seem to the authors that there is a greater probability that in the case of the iron containers the magnetite was peptized to a small extent thereby causing a greater "apparent" dissolved iron concentration. A reduction in the hydrogen ion concentration would not result from this mechanism.

TENSION SPECIMEN SHAPE AND APPARENT STRENGTH

By F. O. Anderegg,[1] Royal Weller[2] and B. Fried[3]

Synopsis

The true maximum stress in a tension specimen is $K \times$ load/area, where K is a correction due to the non-uniformity of stress over the failure section. When the points of load application are well removed from the failure section, K is approximately $1 + \frac{d}{4r}$, where d is the width of the section at the neck, and r is the radius of curvature. Fairly long, slender test specimens are thus indicated. When it seems desirable to use a figure 8 shaped specimen, as in testing cement, very large values of K are found unless the point of load application is made some distance from the center of the specimen. When that is done, a more nearly uniform distribution of stress across the section is secured.

The great variation in shape of tension test specimens specified by the Society for different materials, ranging from the slender shape used in metal testing[4] to the figure 8 shaped cement briquet,[5] in which only about 60 per cent of the true tensile strength is indicated by the usual test, points to the desirability of using recent advances in photoelastic analysis[6, 7] to set up generalizations for more rational design. This is especially timely in connection with the work of Subcommittee I on Strength Properties of the Society's Committee D-20 on Plastics, and is particularly important whenever *brittle* materials are to be tested. The points to consider when establishing requirements for making tension tests include the choice of proper shape to give as close an approximation as is feasible to the true value, as well as ease and cost of fabrication.

Some experiments have been carried out at the Ohio State University Engineering Experiment Station on the effect of the shape of the test specimen upon the apparent tensile strength. The shapes experimented with are shown in Fig. 1.

The measurements were made with photoelastic equipment, using monochromatic, circularly polarized light and specimens freshly cut from transparent phenol-formaldehyde resin (Bakelite BT - 61 - 893), having a sensitivity of 84.7 psi. per in. of thickness per fringe. Photographs of the fringe patterns for the central portions of the several shapes tested are shown in Fig. 2. The results on specimens of various d/r ratios, ob-

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[1] Consulting Specialist on Building Materials, Newark, Ohio.

[2] Instructor in Physics, The Ohio State University, Columbus, Ohio.

[3] Engineering Experiment Station, The Ohio State University, Columbus, Ohio.

[4] Standard Methods of Tension Testing of Metallic Materials (E 8 - 36), 1936 Book of A.S.T.M. Standards, Part I, p. 833.

[5] Standard Methods of Sampling and Testing Portland Cement (C 77 - 32), 1936 Book of A.S.T.M. Standards, Part II, p. 23.

Standard Methods of Testing Gypsum and Gypsum Products (C 26 - 33), *Ibid.*, p. 106.

[6] Max M. Frocht, "Recent Advances in Photoelasticity," P. H. Thesis, University of Michigan, published by Am. Soc. Mechanical Engrs. (1931).

[7] Max M. Frocht, "The Behavior of a Brittle Material at Failure," *Journal of Applied Mechanics*, September, 1936, p. A99.

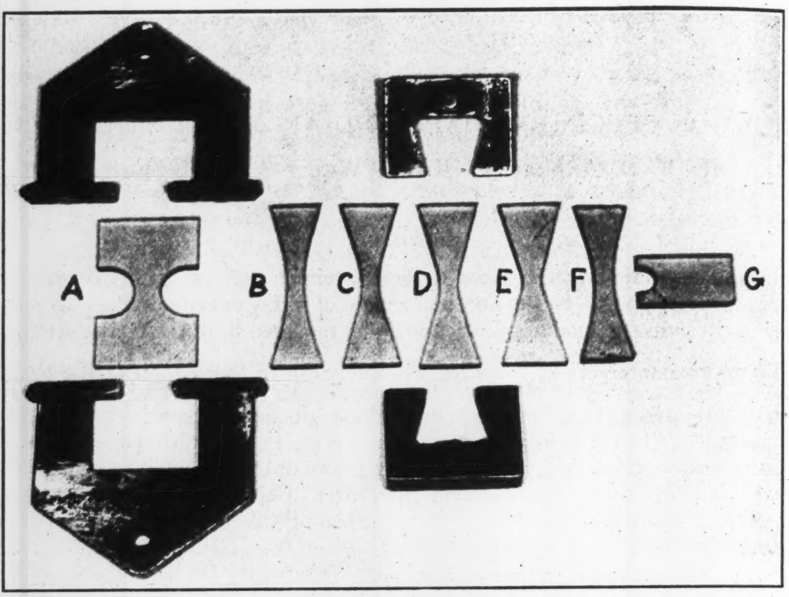
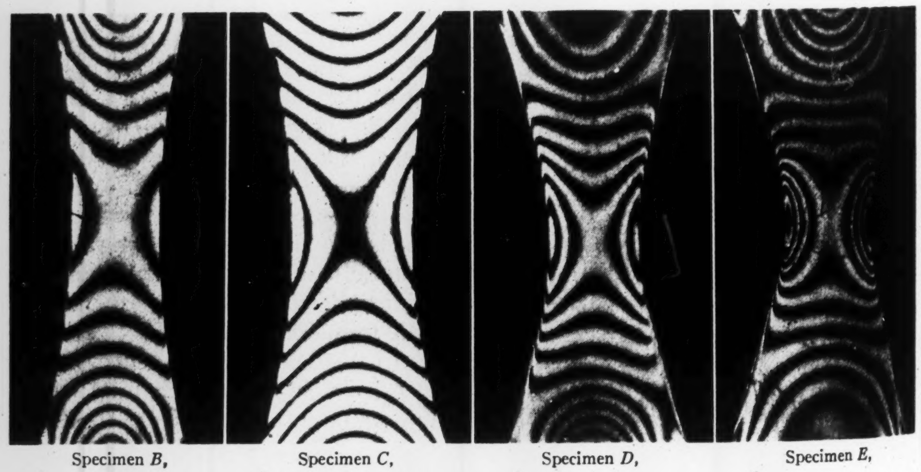


FIG. 1.—Models and Grips Used in Studying the Effect of Shape upon the Apparent Tensile Strength.

A = load application close to the failure section.

B, C, D, E, and F = more slender specimens with load well away from failure section.

G = model of cleavage test for small clear specimens of timber.



Specimen *B*, $\frac{d}{r} = 0.10$, $K = 1.02$.

Specimen *C*, $\frac{d}{r} = 0.125$, $K = 1.03$

Specimen *D*, $\frac{d}{r} = 0.25$, $K = 1.06$.

Specimen *E*, $\frac{d}{r} = 0.50$, $K = 1.13$.

FIG. 2.—Slender Specimens, Load Being Applied Away from the Failure Section.

tained by comparing the increase in fringe order at the edge of the specimen with an increase in applied load, are given in Fig. 3. Results obtained by Frocht[7] with specimens of larger d/r ratios are also included, his load being applied by means of a pin passing through a hole near the end of the specimen. Very good agreement was secured among these results. A smooth curve drawn through the points approximates the equation $K = 1 + d/4r$, where K is the ratio of edge stress to average stress across the section, and hence the correction factor to be applied to the apparent observed strength, while d is the minimum width, and r is the radius of curvature. Photoelastic measurements such as the above can be made with an accuracy of 3 per cent or better.

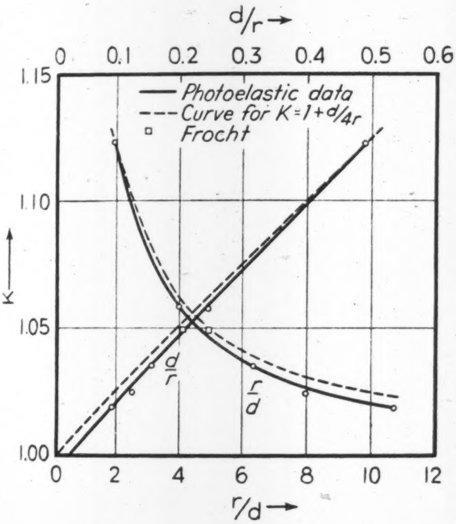


Fig. 3.—Relation of K to $\frac{r}{d}$ and $\frac{d}{r}$ for Grips Well Removed from the Failure Section. $K = 1$ indicates no stress concentration.

Since a preliminary result obtained by one of the authors[8] with the cement briquet shape failed to fall on the curve, the factor of position of application of the load was studied with the wide specimen A shown in Fig. 1. The load was applied at various points in the notch, the positions ranging from 30 to 90 deg. being indicated by the angle θ from the center of the notch. Two of the fringe patterns are shown in Figs. 5 and 6, the pattern at 30 deg. being essentially that obtained with the cement briquet. The results obtained in this investigation are plotted in Fig. 4. The position of application of load had a direct effect on the strength obtained, such that, for this shape, the reciprocal of the difference between the edge stress and the average tensile stress for the whole section was directly proportional to the angle θ.

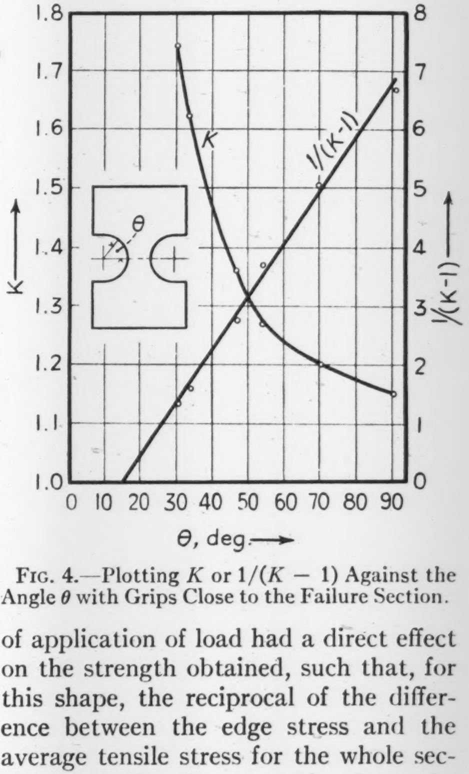


Fig. 4.—Plotting K or $1/(K - 1)$ Against the Angle θ with Grips Close to the Failure Section.

It is evident from Fig. 4 that increasing values of K accompany increasing proximity of the load points to the failure section. This was anticipated since the local disturbances in the immediate vicinity of the load points tend to produce edge tension between these points. Of course as θ decreased the loading forces which presumably act normal to the edge become larger for a given tensile force and increase the effect. However, the values of K for θ greater than about 60 deg. are less than those shown in Fig. 3. This result was not anticipated.

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[8] Royal Weller, "The Cement Briquet," Engineering Experiment Station *News*, The Ohio State University, Vol. 9, February, 1937, p. 13.

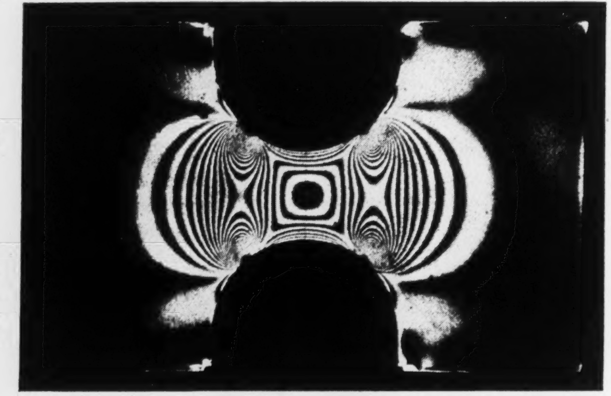

FIG. 5.—Load Application Close to Failure Section and at an Angle θ of 30 deg.
The fringe pattern is essentially that of the cement briquet.

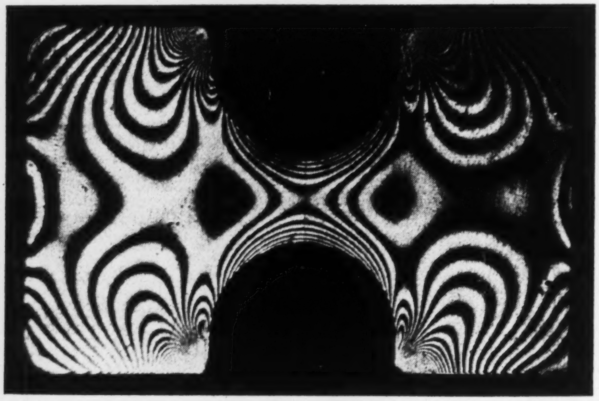

FIG. 6.—Load Being Applied at an Angle θ of 90 deg. and Not Far from the Failure Section.

At first sight as the grips are moved farther and farther out, one might expect that a cantilever action would cause greater edge stress, whereas the reverse was demonstrated.

With the cement briquet, the angle θ is 29 deg., and while the formula $K = 1 + d/4r$ gives the calculated value 1.25, that taken from the curves of Fig. 4 is 1.78. The erratic result referred to previously as having been secured by one of the authors[8] was 1.53, while Coker and Filon[9] (p. 578) observed the value 1.74 for the actual briquet shape and Durand-Claye[10] a value of 1.54. It should be pointed out that a portland-cement mortar is not perfectly elastic and for high loads some flow must take place, *reducing* the apparent strength still farther. To offset this tendency it is customary to apply the load rather rapidly.

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[9] E. G. Coker and L. N. G. Filon, "A Thesis on Photo-elasticity," Cambridge University Press (1931).

[10] Durand-Claye, *Annales des Ponts et Chaussées*, Vol. 9, June, 1895.

As loading takes place in cements and ceramic materials beyond the yield point, the stress-strain curve falls off, indicating some points of incipient failure within the material because of the stress concentration at the apex of such failure points. This effect is opposite to that expected from more plastic materials, in which case a stress redistribution may occur in the other direction tending to reduce K, thereby increasing the failure load. Thus the value of K is of considerable significance in the testing of brittle materials.

The conclusions from this study are to make the specimen as narrow as conveniently practicable and make the radius of curvature as large as convenient. If it seems desirable to use a briquet type of specimen, the grips should be applied as far out from the center of the specimen as possible. Sharp breaks in contour should be everywhere avoided.

Application to Various A.S.T.M. Tension Test Specimens:

The cement briquet[5] has already been discussed. Specimens of various metals, textiles, and rubber generally conform to requirements stated in the last paragraph above.

In plastics[11] the test specimen of molded materials for electrical insulation is so shaped that in one plane d is 1 in. and the radius of curvature r is 3 in., giving a K value of 1.08. In the other plane of the section having a thickness d' of $\frac{1}{4}$ in. and r' of 3 in., a K of 1.02 is obtained and on multiplying these together the total correction factor K becomes about 1.10. Another shape, sometimes used by plastics manufacturers for routine testing, is 3 in. long and has an end section 1 by $\frac{3}{8}$ in. At the narrowest point d is $\frac{1}{2}$ in. and r is 4 in. in one plane and d' is $\frac{1}{4}$ in. and r' is 3 in. in the other plane, from which K for the specimen is calculated to be about 1.05. Curvature in two planes increases the K factor somewhat, but may be desirable for reasons of good molding.

In a method of testing sheet and plate materials used in electrical insulation,[12] a shape somewhat similar to that used in metal testing has been proposed, especially for specimens cut from sheets. In cutting it out, the specimen is to be narrowed down to a straight section $2\frac{1}{4}$ in. long and either $\frac{1}{2}$ or 1 in. wide, the necking down following a curvature with a radius of 3 in. The anticipated point of failure will be close to the narrow end of the curved portion,[6] for which K will be 1.02 to 1.04. This slender type of specimen is good, but it is suggested that the straight part is superfluous. This applies also to brittle metals. In view of experience gained in photoelastic work it is suggested that in cutting specimens from sheets of plastics, great care be taken to use very sharp tools to avoid nicking and heating. In certain materials (notably Bakelite) a cut edge may lose volatile constituents so that in a few hours edge effects of unknown values are set up. These effects are readily observed with a polariscope which may consist simply of a pair of Polaroid plates.

In testing small clear timber specimens,[13] the test for tension perpendicular to grain is made on very short specimens, as is also the case in the test for cleavage. In the former d is 1 in. and r is $\frac{1}{4}$ in. The grips contact a considerable area and according to the degree of contact between the wood and the grips, *K* would vary probably between, say, 1.5 to perhaps as much as 3.0. Coker and Filon[9] (pp. 637–641) observed experimentally for this shape a *K* value of 1.88 with grips of $\frac{1}{8}$ in. radius, the load being applied at an angle θ of 90 deg. The significant feature of the cleavage test is the ratio of the stress at the base of the notch to the force applied. This we found with the specimen *G* of Fig. 1 to be about 5.8. That is, a load of *P* pounds per inch of thickness produces a stress of 5.8 psi. for a piece of standard dimensions.

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[11] Standard Methods of Testing Molded Materials Used for Electrical Insulation (D 48 - 33), 1936 Book of A.S.T.M. Standards, Part II, p. 1192.

[12] Tentative Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 38 T), *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 1046 (1938); also 1938 Book of A.S.T.M. Tentative Standards, p. 1181.

[13] Standard Methods of Testing Small Clear Specimens of Timber (D 143 - 27), 1936 Book of A.S.T.M. Standards, Part II, p. 465.

Coker and Filon[9] (pp. 631–636) obtained a *K* value of 6.6 for a Xylonite model of this same shape. On loading to destruction, our model broke as indicated by the dotted line on *G*, but failure in timber, of course, would be by splitting.

In testing tension parallel to grain, very slender specimens are used and the probable point of failure would be where the tapered sections change to one that is uniform, because of stress concentration at the edges. It is suggested that a specimen could be turned in a lathe to a similar minimum diameter, say $\frac{3}{4}$ in., and with a radius of curvature of, say, 3 in. to good advantage. *K* is then about 1.06.

DISCUSSION

MR. THOMAS J. DOLAN[1] (*presented in written form*).—The authors have presented a good argument for the inclusion of large-radius fillets on tension test specimens of brittle materials. Even on carefully prepared specimens, with fillets of large radius, the localized stresses present invariably cause specimens of brittle material to fail prematurely and the true breaking strength of the material cannot be accurately calculated from test results.

These localized stresses are also significant when testing ductile materials subjected to repeated loadings. In some recent repeated tension fatigue tests conducted at the University of Illinois on ductile steel specimens having a straight portion 5 in. wide and with 9-in. radius fillets at the ends where the member was widened at the grips, it was observed that the specimens failed at the fillets in almost every case. A check on the stress by the photoelastic method showed a stress concentration factor, K, for the fillet to be 1.12 (for $r/d = 1.8$). Computing this value by the authors' formula $K = 1 + d/4r$ the factor is 1.14, which shows close agreement. This small concentration factor was enough to cause the failure to localize at the fillets; even with 9-in. radius fillets the true fatigue strength of the steel could not be obtained.

The authors' statement that the photoelastic stress analysis can be made with an accuracy "of 3 per cent or better" does not seem justified in view of the experimental difficulties pertaining to the method. Small initial stresses in the bakelite, and additional induced residual stresses that form around the edges of a model soon after cutting, are likely to lead to some error. For example, in the authors' Fig. 2 specimens *D* and *E* show an abrupt curvature of the fringes at the boundaries of the model indicating residual edge stresses. The exact determination of the fringe order at the edge of the model (where the maximum stress occurs) is especially hard to determine since the edge is sometimes partially obscured in the photograph.

For models in which the maximum stress is not more than 15 per cent greater than the average stress on a section (as in the results shown in Fig. 3 of the paper) it is essential that the maximum fringe order be determined with great accuracy since the probable errors introduced in the experimental technique are approaching the magnitudes of the true difference between the average and maximum stresses. The writer believes that with carefully prepared models and well developed testing technique, the photoelastic method should be accurate within 5 to 10 per cent which, after all, is less than the probable variation in strength of test specimens of structural materials (to which the results of the analysis are to be applied).

MESSRS. F. O. ANDEREGG,[2] ROYAL WELLER[3] AND B. FRIED[4] (*authors' closure*

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[1] Assistant Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[2] Consulting Specialist on Building Materials, Newark, Ohio.

[3] Instructor in Physics, The Ohio State University, Columbus, Ohio.

[4] Engineering Experiment Station, The Ohio State University, Columbus, Ohio.

by letter).—It is gratifying to see Mr. Dolan's figure of 1.12 so close to the formula. We believe that 3 per cent is a fair figure of what to expect from the photoelastic method. The fringe distortion due to any initial stresses need not affect the accuracy of the results if the *increase* in fringe order due to a given *increase* in load is used, because any initial conditions, which might appear to offer complications, will cancel out. The fringe order at the edge of the model can be read quite closely if a light field instead of a dark field photograph is taken.

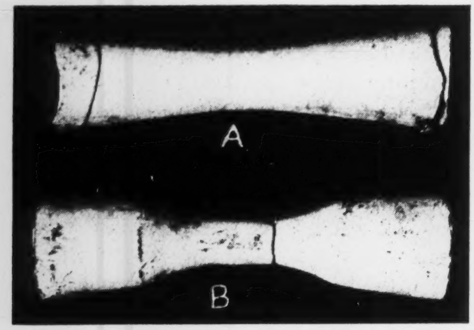

FIG. 1.—Tensile Strength of Porcelain Could Not be Determined with Specimen *A* Due to Breaking Under the Grips. By necking down the center, while maintaining a reasonable radius of curvature, adequate results were obtained.

In testing tensile strength of vitreous dinnerware porcelain, W. C. Bell of the Ohio State University Engineering Experiment Station encountered difficulty in using the shape prescribed for testing electrical porcelain in A.S.T.M. Methods D 116 - 39.[5] On gripping, as required, the ends of his specimens kept breaking off irregularly, as shown in the accompanying Fig. 1. The stress concentration was so much greater under the grips than in the smallest section that little idea could be obtained as to tensile strengths. By narrowing down the section, but maintaining a radius of curvature greater than 2 in., breaks were obtained near the middle and at values within the usual scatter of ± 20 per cent obtainable with such brittle materials.

A manufacturer of insulators for mine trolleys complained to the company supplying the laminated paper stock that he was getting only half the strength they had led him to expect. He was placing the rods in a lathe and turning grooves and then spinning copper tubing into the grooves for grips. The supplier then broke three specimens, the one with a V notch giving the 6000-lb. strength obtained by the insulator fabricator. A square notch with sharp corners gave the same result, while a U notch, as had been previously used, required 13,000 lb. to break. For this shape *K* was calculated to be 1.85, from data given by Frocht,[6] indicating a true tensile strength of about 24,000 psi. Based on the results obtained in the paper above, a new specimen was prepared (the bottom one of the accompanying Fig. 2) with a 3-in.

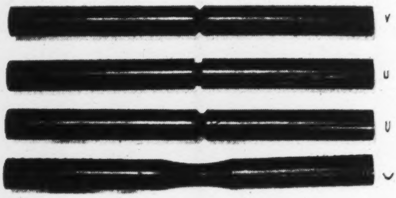

FIG. 2.—Laminated Paper Stock with a V or Square Groove Has About Half the Strength of the Same Rod with a U Notch, Which, in Turn, Has Only About Half the True Strength for the Section.

V notch—6000 lb.; Square notch—6000 lb.; U notch—13,000 lb.; 3-in. radius of curvature—23,000 lb.

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[5] Standard Methods of Testing Electrical Porcelain (D 116 - 39), 1939 Book of A.S.T.M. Standards, Part III, p. 284.

[6] Max M. Frocht, "The Behavior of a Brittle Material at Failure," *Journal of Applied Mechanics*, September, 1936, p. A99.

radius of curvature, for which the *K* factor would be about 1.04. The observed value of 23,000 lb. should then be corrected to 24,000 lb., the value also calculated from the U notch. The insulator fabricator was apparently losing about three-fourths the potential strength of the stock.

The empirical formula given in this paper cannot be expected to hold for narrow notches, but only where *r* is rather large.

ANALYSIS OF ROCKWELL HARDNESS DATA

By R. L. Peek, Jr.,[1] and W. E. Ingerson[1]

Synopsis

An analysis made of the Rockwell hardness test (*a*) to correlate readings made with different loads and ball diameters, and (*b*) to simplify the relation between hardness and tensile strength measurements.

For any one homogeneous material, dimensional analysis and comparison with Meyer's law indicates that for small values of $\frac{h}{D}$

$$\frac{h}{D} = \left(\frac{C\,(W - W_0)}{SD^2}\right)^{1/m}$$

where h is the differential depth of indentation made by a ball of diameter D acted on by a major load W, the minor load being W_0, S is some constant of the material having the dimensions of a stress, and C and m are dimensionless constants.

Experiments are reported in which samples of various materials of several tempers were tested with different loads and ball diameters and the tensile strength of the specimens subsequently determined. In each case good agreement was obtained for the relation set forth above for $\frac{h}{D} < 0.1$.

The results indicate the possibility of:

1. Calibrating the Rockwell tester with a single test block, using various loads and ball diameters.
2. Setting up specification limits for hardness measurements corresponding to tensile strength limits.

The Rockwell hardness test has been developed and employed on a purely empirical basis. The related Brinell test, on the other hand, has been subjected to extensive investigation along the lines first developed by Meyer.[2] These studies have led to the empirical law:

$$\frac{W}{D^2} = A\left(\frac{d}{D}\right)^n \quad \ldots\ldots\ldots (1)$$

which gives the relation between the applied load W, the ball diameter D, and the diameter d of the indent, in terms of two constants of the material tested, A and n.

In O'Neil's text[3] is given a review of the studies that have been made of the application of this relation. These have shown that n is a quantity measuring the strain-hardening properties of the material, having a limiting value of 2.0 for materials showing little or no strain hardening. A, which has the dimensions of a stress, is related to the stress required for plastic deformation. In particular, it has been shown[4] that for non-ferrous sheet materials, there is a linear relation between A and tensile strength.

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[1] Members of Technical Staff, Bell Telephone Laboratories, New York City.

[2] E. Meyer, "Hardness Testing and Hardness," *Zeitschrift* des Vereines deutscher Ingenieure, Vol. 52, p. 645 (1908).

[3] H. O'Neill, "The Hardness of Metals and Its Measurement," Chapman & Hall, London (1934).

A relationship of the type of Eq. 1 has an obvious value in laboratory studies in facilitating the interpretation of hardness measurement in comparative studies of materials. It has a further and more immediately practical value in correlating measurements made with different loads and different ball sizes and in facilitating the correlation of hardness measurements and such properties of the material as tensile strength. The work reported here has been directed to determining whether a relation similar to Eq. 1 applies to the Rockwell test.

Analysis:

In the Brinell test the quantity measured is the diameter d of the indent after removal of the load. If the indent were truly spherical and bounded by the plane of the original surface, there would be a simple geometrical relation between d and h, the depth of the indent, given by:

$$\frac{h}{D} = \frac{d^2}{4D^2} + \frac{h^2}{D^2} \ldots\ldots \quad (2)$$

If this relation applied strictly, for small values of h/D this latter quantity would be approximately proportional to d^2/D^2, so that from Eq. 1 (for $n = 2$) W/D^2 would be directly proportional to h/D. Actually, the indent is not strictly spherical, and in general its bounding plane does not coincide with the original surface. For any exact determination of the relation between h and W, recourse must be had to experiment. Studies by Devries[5] and Batson[6] have indicated an approximately linear relation between h/D and W/D^2 when $h/D < 0.1$.

In any case, the form of the relation between h and W must conform to dimensional requirements. Assuming dynamic and creep effects to be excluded, time does not enter the relation, and h is a function only of ball diameter D, load W, and those properties of the material which affect its behavior in the test. The latter are the quantities which characterize the stress-strain relation and include therefore Young's modulus E, the yield stress in shear S_0, the tensile strength S, and one or more dimensionless parameters p_1, p_2, etc., characterizing the shape of the stress-strain curve. It follows, therefore, that h is a function of W, D, E, S, S_0, and p_1, p_2, etc. From dimensional considerations, this relation must be of the form:

$$\frac{h}{D} = f\left(\frac{W}{SD^2}, \frac{E}{S}, \frac{S_0}{S}, p_1, p_2 \cdots\right). \quad (3)$$

Now for any one material E/S, S_0/S, and p_1, p_2, etc., are constants. In this case, then, h/D is a function of W/SD^2 only. This important conclusion depends only on the truth of the assumptions that (*a*) the result is independent of the time, (*b*) the result is independent of the thickness of the sample, and (*c*) the material is homogeneous. If these conditions are satisfied all values of h/D, for all values of W and D, must lie on the same curve when plotted against W/D^2. For different materials, of course, the curves are not necessarily similar.

In the case of the Rockwell test, the quantity measured is h_1–h_0, where h_0

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[4] H. N. Van Deusen, L. I. Shaw and C. H. Davis, "Physical Properties and Methods of Test for Sheet Brass," *Proceedings*, Am. Soc. Testing Mats., Vol. 27, Part II, p. 173 (1927).

[5] R. P. Devries, "Comparison of Five Methods Used to Measure Hardness," *Technologic Paper No. 11*, Nat. Bureau Standards (1912).

[6] G. C. Batson, "Hardness Test Research—Static Indentation Test," *Proceedings*, Inst. Mechanical Eng. (British), Vol. 1, p. 401 (1923).

is the indentation under the minor load W_0 and h_1 is the indentation under the major load W, measured with W_0 applied, but with the balance of the major load removed. The data therefore do not permit a direct plotting of h/D *versus* W/D^2 to determine the relation between them. Instead, it is necessary to assume a form for this relationship from which an expression for h_1–h_0 may be derived and to compare this with observed values of h_1–h_0.

In the tests reported here, experimental data were compared with a relation derived from the assumption:

$$\frac{h}{D} = \left(\frac{CW}{SD^2}\right)^{\frac{1}{m}}$$

where C and m are constants of the material. As noted above, this relation should be in approximate agreement with Meyer's law (Eq. 1) if h/D is small. From the approximate geometrical relation between h and d (Eq. 2), m should be near one if n is near two, and hence,

$$\frac{h}{D} = \left(\frac{C(W - W_0)}{SD^2}\right)^{\frac{1}{m}} \ldots\ldots (4)$$

where, for brevity, h is now written for h_1–h_0, the penetration measured in the Rockwell test. This relation was chosen for study rather than the relation of direct proportionality reported by Devries,[5] as the latter is merely a special case of the above equation for which $m = 1$.

Experimental:

A series of measurements were made on various samples, using a standard Rockwell hardness tester, and balls of $\frac{1}{16}$, $\frac{1}{8}$ and $\frac{1}{4}$-in. diameters, with major loads of 60, 100, and 150 kg., the minor load being 10 kg. in each case. Readings were made on the red scale (normally used for Rockwell "B" readings). By subtracting the reading in scale divisions from 130 and multiplying the resulting values by 2×10^{-4}, values of h were obtained expressed in centimeters. Some measurements were made on a superficial tester, using a ball of $\frac{1}{16}$-in. diameter, with major loads of 15, 30, and 45 kg. and a minor load of 3 kg. The scale readings were subtracted from 100 and multiplied by 10^{-4} to give h in centimeters.

The materials tested were:

3 Standard hardness blocks and
Tension test specimens of
  Aluminum
  Mild steel
  6 tempers of grade A brass
  4 tempers of grade B nickel silver
  3 tempers of grade C phosphor bronze and
  5 thicknesses of half hard grade B nickel silver

With the exception of the last item and the aluminum specimens (0.064 in. thick) all tension test specimens were 0.040 in. thick. Young's modulus and tensile strength determinations were made on each tension specimen after the hardness measurements had been made. The tension specimens were made and the tests conducted in accordance with the A.S.T.M. Standard Methods of Tension Testing of Metallic Materials (E 8 -- 36). Five hardness readings were made on each specimen. Two specimens of each material were tested. The differences between paired specimens were not significant, and averaged values are reported below.

For each material, values of h/D were plotted against values of $(W - W_0)/D^2$ on logarithmic paper. The data for the standard hardness blocks are shown in Fig. 1, those for mild steel and aluminum in Fig. 2, and those for grade A brass in Fig. 3. Similar agreement with Eq. 4 was obtained for the nickel silver and phosphor bronze samples.

The data for the standard hardness blocks afford the best test of agreement of the data with Eq. 4 as they include measurements with all three ball diameters. Each point in Fig. 1 represents the mean of five readings. The standard deviation of each group of five readings was computed and expressed as a percentage. These standard deviations were averaged for each specimen, giving in each case a mean value of the order of 1 per cent. The maximum error should therefore be of the order of 3 per cent. The deviations of the points from the lines fitted to them are within this, with the exception of one point ($h/D = 0.0058$) for block No. 163, and one point ($h/D = 0.0153$) for block No. 563. The individual standard deviations for these points were 4.4 per cent and 0.9 per cent, respectively. The deviation of the former point is therefore within the indicated range of error, while that for the latter is apparently significant. As can be seen from Figs. 2 and 3, apparently significant deviations occurred in a number of cases for values of h/D in excess of 0.1. The differences between m and one observed for blocks Nos. 663 and 563 are large enough to warrant the use of Eq. 4 in preference to the equation for which $m = 1$.

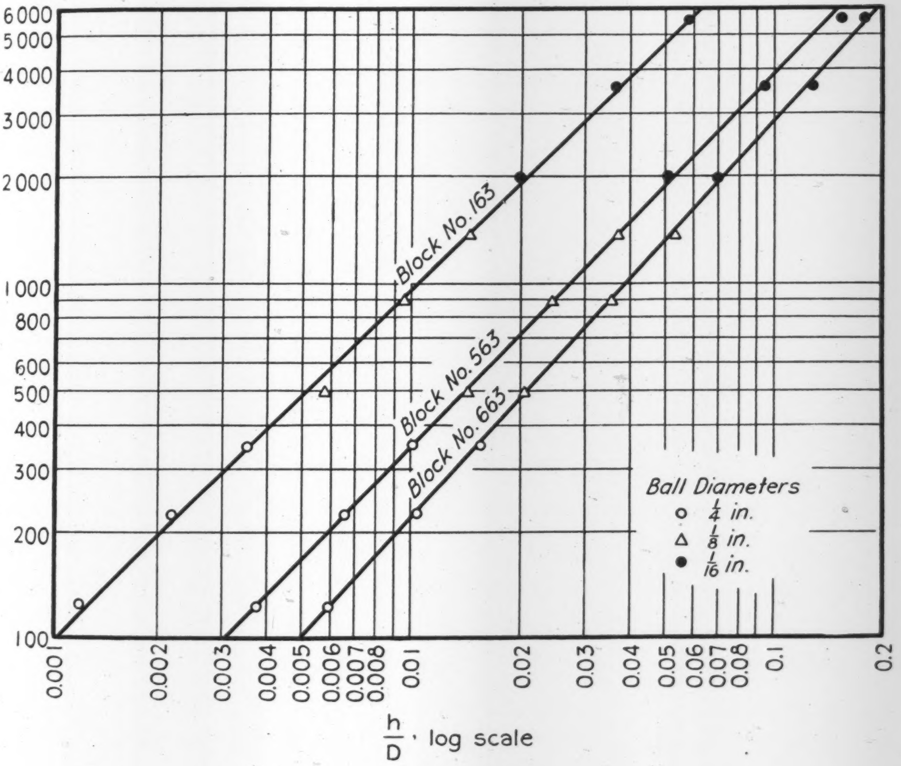

FIG. 1.—Converted Rockwell Readings.
Standard test blocks.

The data therefore indicate that, for the materials tested, Rockwell hardness readings conform to Eq. 4 for values of

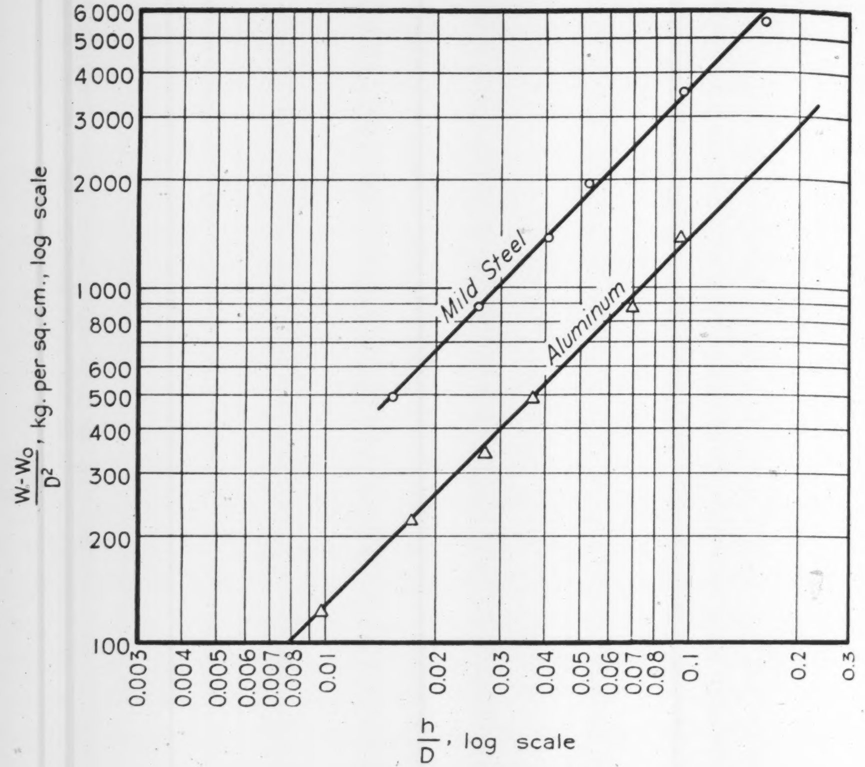

FIG. 2.—Converted Rockwell Readings.
Mild steel and aluminum.

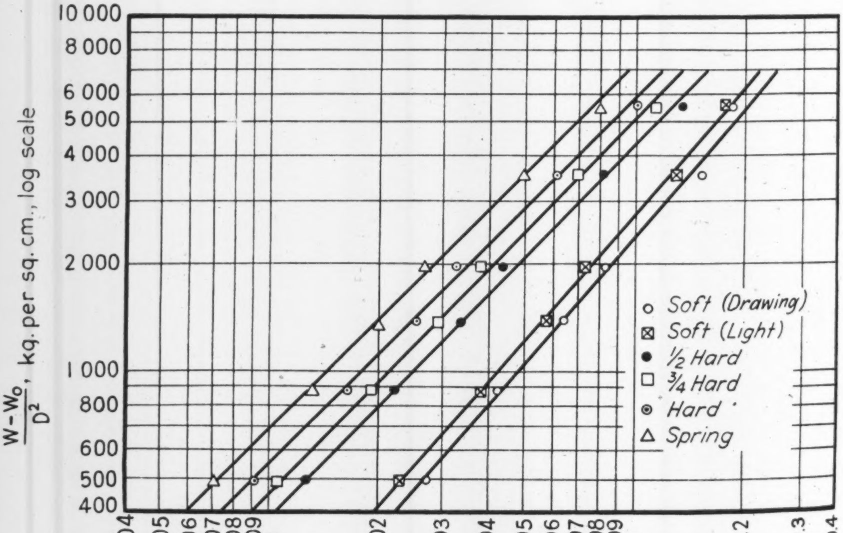

FIG. 3.—Converted Rockwell Readings.
Grade A brass sheet.

h/D below 0.1. Small but apparently significant deviations occur for values of h/D between 0.1 and 0.2. No readings were made for values of h/D greater than 0.2. It is of interest to note that for the standard Rockwell "B" test a $\frac{1}{16}$-in. ball is used, for which $D = 0.1588$ cm., so that for $h/D = 0.1$, $h = 0.0159$ cm. This corresponds to a Rockwell "B" reading of 130 – 80 or B50. The larger deviations therefore occur only for materials softer than B50.

TABLE I.

Sample	E/S	S, kg. per sq. cm. $\times 10^3$	m	C	C'
Block No. 663	.....	.....	1.122	....	....
Block No. 563	.....	.....	1.055	....	....
Block No. 163	.....	.....	1.000	....	....
Mild steel	6.73	3.11	1.059	0.0747	0.0706
Aluminum	5.93	1.17	1.034	0.0788	0.0762
Grade A brass:					
Soft (drawing)	3.09	3.22	1.182	0.0894	0.0756
Soft (light)	3.49	3.55	1.172	0.0880	0.0751
½ hard	2.74	3.94	1.050	0.0817	0.0778
¾ hard	2.39	4.55	1.050	0.0802	0.0764
Hard	2.14	5.07	1.026	0.0821	0.0799
Spring	1.63	6.52	1.031	0.0835	0.0809
Grade B nickel silver:					
Soft	3.63	4.06	1.085	0.0990	0.0913
½ hard	3.09	5.03	1.030	0.0808	0.0785
Hard	2.06	6.97	1.040	0.0815	0.0784
Extra hard	1.96	7.54	1.033	0.0803	0.0776
Grade C phosphor bronze:					
½ hard	2.46	5.14	1.060	0.0770	0.0726
Hard	1.79	6.60	1.055	0.0735	0.0704
Spring	1.47	7.60	1.043	0.0738	0.0708

Relation to Tensile Strength:

From the lines drawn to fit the data of Figs. 1, 2, and 3 and from the corresponding data for the other samples tested, values of m and C have been computed, S being taken as the tensile strength. The resulting values of S, m, and C are listed in Table I. Values of S were not available for the standard hardness blocks, and only values of m are reported for them.

If the experimental finding that Eq. 4 applies to all the materials studied is taken in conjunction with Eq. 3, which is the consequence of dimensional requirements, it follows that C and m should each be functions of E/S, S_0/S and p_1, p_2, etc. The parameters p_1, p_2, etc., reduce to general constants if all the materials have stress-strain curves of similar types, which is roughly true. It follows then that C and m should be functions of E/S and S_0/S.

Now S_0/S measures the relation between initial and final values of stress required for plastic deformation, that is, is a measure of strain hardening. As studies of the Brinell test by Meyer's analysis have indicated that the deviation of n from two is a measure of strain hardening, it would appear that the deviation of m from one is a similar measure. In agreement with this it will be seen from Table I that the values of m for the hardened samples are near one, while those for the annealed materials are significantly higher.

It may be concluded that for very hard materials, for which the stress required for plastic deformation is constant, Eq. 4 should apply with $m = 1$. It follows that the same relation should apply to a differential change in h if S', the effective average plastic stress applied, is substituted for S, so that:

$$d\left(\frac{h}{D}\right) = \frac{C'd(W - W_0)}{S'\,D^2}$$

where C' is the value of C for S constant.

Now S will vary with the effective average strain in the manner of the stress-strain relation, and the effective average strain will be some function of h/D. If then it is assumed that,

$$S' = S\left(\frac{h}{D}\right)^k \quad \ldots\ldots\ldots (5)$$

where S is the maximum value of S' and k is a constant, substitution in the preceding equation and integration leads to the relation:

$$\left(\frac{h}{D}\right)^{1+k} = \frac{(1 + k)\,C'(W - W_0)}{SD^2} \quad \ldots (6)$$

This is identical with Eq. 4 with $1 + k$ written for m and with $(1 + k)C'$ written for C. Values of C', or C/m, are included in Table I.

Equation 6 follows from Eq. 4 on the assumption that $m = 1.0$ in the latter equation when the stress required for plastic deformation has the constant value S, together with the assumption that the (variable) average effective stress is given by Eq. 5. The latter assumption can be only approximately true but (for k or $m-1$ small) is in accord with the general nature of strain hardening as shown by stress-strain curves.

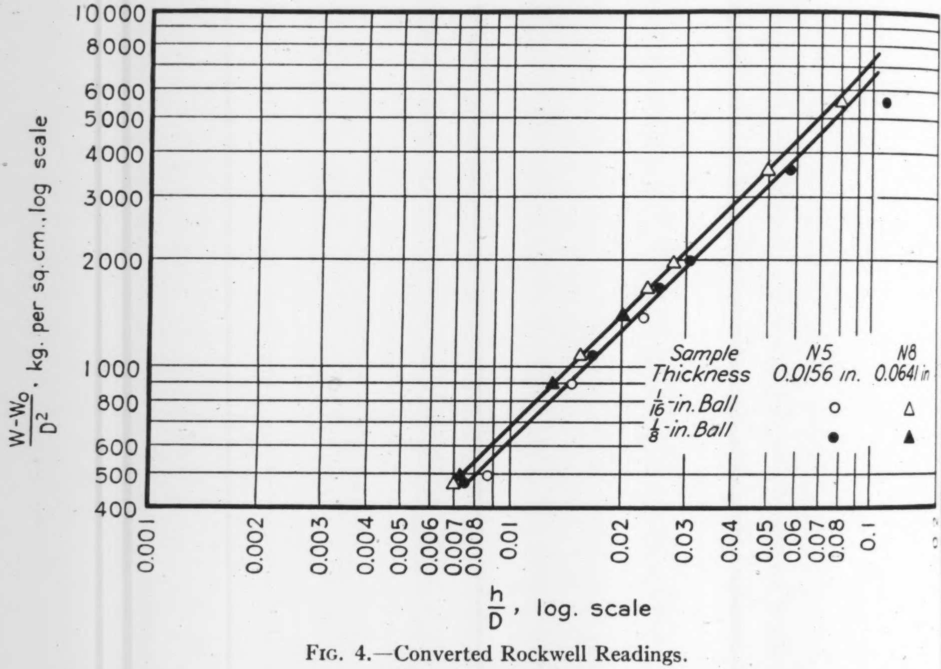

FIG. 4.—Converted Rockwell Readings.
Effect of sample thickness.

From the dimensional argument, C should be a function of E/S and S_0/S. In Table I, however, it can be seen that for all materials tested, the values of C lie within the range 0.075 to 0.085, with the exception of the three annealed samples (two brass and one nickel silver). The values of C' all lie within the range 0.070 to 0.080, with the exception of the one annealed nickel-silver sample (for which $C' = 0.0913$).

Values of E/S are included in Table I. Comparison of these with the corresponding values of C or C' gives no evidence of correlation. It appears therefore that C and C' are independent of E/S and (taking $m-1$ as a measure of S_0/S) that C' is independent of S_0/S, while $C = mC'$.

The indicated range of variation for C' corresponds to an extreme deviation from the mean of 5 per cent. This same order of deviation is to be observed in the deviation of individual points from the plotted lines in Figs. 2 and 3, and it may be concluded that C' is a constant, independent of the material, within the order of accuracy with which Eqs. 4 and 6 fit the data. This deviation of 5 per cent is larger than that observed for the standard test blocks and corresponds to a deviation of 1.5 points on the Rockwell "B" scale at B100, or 4 points at B50. The larger variability for the sheet specimens, as compared with the test blocks, is most readily explained as the result of inhomogeneity of the material.

Effect of Sample Thickness:

Hardness and tensile strength measurements were made on five samples of $\frac{1}{2}$ hard grade B nickel silver, ranging in thickness from 0.0156 in. to 0.064 in. As in the other tests, duplicate specimens were used in each test. For these samples, measurements were made with the Superficial tester as well as with the standard Rockwell tester.

TABLE II.

Sample	Thickness, in.	S, kg. per sq. cm. $\times 10^3$	m	C	C'
N5..........	0.0156	6.01	1.029	0.0852	0.0830
N6..........	0.0201	6.27	1.005	0.0940	0.0933
N2..........	0.0403	5.05	1.019	0.0831	0.0817
N8..........	0.0641	5.90	1.031	0.0740	0.0716

Data for the two limiting thicknesses are shown in Fig. 4. The points plotted represent readings at three loads with the $\frac{1}{8}$-in. ball and six with the $\frac{1}{16}$-in. ball, of which the three lower loads were made on the Superficial tester. Good agreement with Eq. 4 was shown throughout by the results for the 0.064-in. sample, while with the 0.0156-in. sample the data are more variable and the result for the largest value of h/D is well off the line fitting the other points. Similar results were obtained for the three intermediate thicknesses, except that the divergence of the point for the highest value of h/D was less.

The values of m, C, and C' obtained were as shown in Table II. (A fifth sample included had a thickness of 0.025 in. As the results for this were substantially the same as those for the 0.020-in. sample, they have not been included.)

The values of C' for the thickest sample (N8) lies in the same range (0.070 to 0.080) as the values of C' in Table I. For the other samples, the values of C' are somewhat higher, that for sample N6 being further out of line than the others. The plotted data, as illustrated by that for sample N5 in Fig. 4, also indicate that (*a*) the data for the thinner samples are more variable, (*b*) there is a greater divergence from Eq. 4 at high values of h/D, and (*c*) in the same range of values of h/D, the values of this quantity for the $\frac{1}{8}$-in. ball are somewhat higher and correspond therefore to higher values of C or C' than do those for the $\frac{1}{16}$-in. ball. These results are consistent with those obtained in the extensive studies of the relation between Rockwell hardness and tensile strength reported by Townsend, Straw, and Davis.[7] The studies showed that the thickness had little apparent effect on hardness for thicknesses of 0.040 in. or more, while for lower thicknesses the results were more variable and the average hardness for a given value of tensile strength was lower (that is h/D larger), an effect which became pronounced at thicknesses of 0.020 in. or less.

The divergence from Eq. 4 at high values of h/D presumably represents the effect of thickness proper—that is, the anvil effect, or the effect on apparent hardness of a thickness too small for the strain to become negiligible at the lower surface of the specimen. However, this divergence is confined to values of h/D greater than 1/10, which, as noted above, are throughout in doubtful agreement with Eq. 4.

The other differences noted with thin

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[7] J. R. Townsend, W. A. Straw and C. H. Davis, "Physical Properties and Methods of Test for Some Sheet Non-Ferrous Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 29, Part II, p. 381 (1929).

specimens seem more readily explained as the result of variation of hardness with depth. The hardness test results must be determined largely by the behavior of the outer layers of the material, which, in a cold-worked specimen, are harder and stronger than the inner layers. The value of S applying to the hardness test is therefore higher than that applying to the inner layers and is therefore higher than the average value given by the tensile strength. The thinner the specimens, the less should be the difference between the value of S in the outer layers and the average value. It is therefore to be expected that the values of C computed from the tensile strength should be higher for the thinner samples.

Similarly, if the value of S decreases in going toward the interior of the sample, for the same values of $W-W_0/D^2$, h/D will be larger for larger values of D, which correspond to a deeper penetration and hence to a smaller value of S. The slightly larger values of h/D for the $\frac{1}{8}$-in. ball, as compared with those for the $\frac{1}{16}$-in. ball, shown for sample N5 in Fig. 4, are consistent with this hypothesis. That no such difference is apparent for sample N8 (0.0641 in. thick) indicates that this sample is more nearly homogeneous or that hardness does not vary so rapidly with depth in the thicker specimens. A rapid variation of hardness with depth in thin specimens would also tend to greater variability in the measured hardness of such specimens.

Alternatively, however, the relatively greater penetration with the larger ball diameter in thin specimens may be caused by an anvil effect, as the fraction of total thickness penetrated will be greater, for a given h/D, the greater the ball diameter. It should perhaps be noted that the anvil effect should give a low apparent hardness, as the direction of flow is largely normal to the axis of penetration, and will be resisted less by the friction between the lower surface of the specimen and the anvil than by the cohesion of the material itself.

In order to separate the effect of thickness proper from that of the variation of hardness with depth, some tests were made with various thicknesses of annealed grade A brass, identical with those made with various thicknesses of half hard nickel silver, reported in Table II. The results are shown in Table III.

It will be noted that the values of C' for all these specimens are in agreement with those reported for the thicker specimens. This shows that the slightly higher values of C' reported for the thinner nickel silver specimens in Table II are, as suggested above, caused by variation of hardness with depth, and are not the result of any anvil effect.

TABLE III.

Thickness, in.	S, kg. per sq.cm. $\times 10^3$	m	C	C'
0.0096	3.303	1.147	0.0855	0.0745
0.0168	3.291	1.160	0.0911	0.0785
0.0323	3.306	1.147	0.0958	0.0835
0.0684	3.210	1.180	0.0890	0.0754

It was also found that with these annealed specimens the results with both the $\frac{1}{16}$-in. ball and the $\frac{1}{8}$-in. ball lay on a common straight line (with the exceptions noted below). This shows that the relative displacement of the straight lines for the two balls noted on the nickel silver specimens are also caused by the variation of hardness with depth.

It was also found that for penetrations exceeding a certain fraction of the thickness of the specimen the plotted points no longer lay on a straight line. This is clearly a result of the anvil effect.

The behavior described in the two preceding paragraphs is most clearly shown in the results for the 0.0096-in. specimens, given in Fig. 5. Here it can be seen that the points for both ball sizes determine a common straight line, from which deviations resulting from the anvil effect are shown by the upper point for the $\frac{1}{8}$-in. ball and the two upper points for the $\frac{1}{16}$-in. ball. These points correspond to ratios of penetration to sample thickness of 0.55, 0.50 and 0.67, respectively. It appears, therefore, that the anvil effect results in deviations from the linear relation for values of penetration of half the specimen thickness or more.

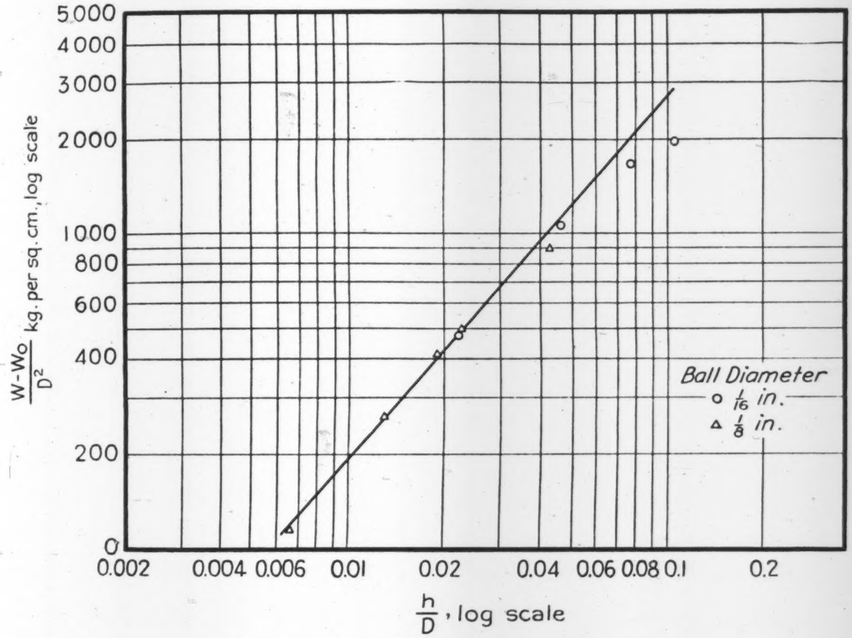

FIG. 5.—Converted Rockwell Readings.
Annealed Grade A brass sheet specimen 0.0096 in. thick.

Taken in conjunction with the results previously given, these data lead to the following conclusions:

Indentation hardness readings are affected by the thickness of the specimen (anvil effect) when the penetration is half the thickness or more. The effect is evidenced by a departure from a straight line relation in the plot on logarithmic paper of $(W-W_0)/D^2$ *versus* h/D, the plot becoming concave toward the axis of h/D.

Variations of hardness with depth are evidenced by a relative displacement of the straight lines obtained on such a plot with different size balls. Such variation is sharper with thin specimens than with thick ones.

Conclusions:

The data here analyzed lead to the following:

1. For the Rockwell hardness test on homogeneous materials of the types studied, the relation between the difference in penetration (h), the major and minor loads (W and W_0, respectively), and tensile strengths for

ball diameter D is given by Eq. 4, where C and m are constants of the material.

2. The quantity $m-1$ is a measure of the work-hardening properties of the material similar to the quantity $n-2$ in the Meyer analysis of the Brinell test.

3. The quantity C is a function of the work-hardening properties of the material and is given approximately by mC', where C' is a numerical constant having a value in the range 0.070 to 0.080. This estimate of C' is based on data taken from tensile strength specimens 0.040 in. thick. The thickness data indicate that this indicated value of C' has been affected by variations in hardness with depth, and that for materials of uniform hardness C' would be slightly higher.

4. Tests on a few samples of different thicknesses indicate that Eq. 4 applies (for $h/D < 0.1$) to sheet material down to 0.0156 in. in thickness, in the range of loads and ball diameters employed in the Rockwell test. It appears, however, that for thin specimens the apparent value of C' is higher, corresponding to the fact that the average value of S is closer to that for the surface layers than is the case for thicker specimens. It also appears that the penetration is relatively larger for larger ball diameters, corresponding either to a more rapid variation of hardness with depth or to an anvil effect with larger ball diameters.

These conclusions must in part be regarded as tentative, particularly those relating to the effects of thickness, which are based on a limited amount of data. Assuming these conclusions to be supported by further studies, the following possible applications of them may be noted:

1. It should be possible to facilitate calibration of a Rockwell tester by employing a single test block and taking readings with various loads, as compared with the present practice of using a different block for each point to be checked in calibration.

2. Use of Eq. 4 should facilitate the development of limits on hardness readings in specifications designed for the control of tensile strength.

3. From Eq. 5, hardness measurements can be employed to determine the tensile strength of a specimen, it being only necessary to determine m and C'/S from data plotted in the form of h/D versus $(W-W_0)/D^2$ on logarithmic paper. As C' is known approximately from the data given here, S can be computed from the measured value of C'/S. This is applicable to a specimen of unknown composition, but should obviously be applied only to materials similar in character to those studied here unless further information extending the application of this work is available.

4. Variations of hardness with depth can be detected by making measurements with different ball diameters in the same range of values of h/D. Failure of the points to lie on a common curve is an indication of variations of hardness with depth, at least for samples over 0.040 in. thick.

Acknowledgment:

The authors are indebted to J. R. Townsend and C. H. Greenall of these Laboratories, whose advice and cooperation have constituted a valuable contribution to this work.

ROCKWELL HARDNESS OF CYLINDRICAL SPECIMENS

By W. E. Ingerson[1]

Synopsis

A theoretical method for correcting the apparent Rockwell hardness numbers obtained on cylindrical specimens using the ball penetrator is developed. The deviation of apparent from true hardness is found to vary approximately linearly with the depth of impression for a given specimen diameter. It has been calculated for various specimen diameters from $\frac{1}{8}$ in. to 1 in.

Experimental results of tests on specimens from $\frac{1}{8}$ in. to 1 in. in diameter of various materials, using the Rockwell "B," "F," and "G" scales are presented. The variation in apparent hardness measured on flat and curved surfaces is found to check the theoretical difference, in general, closer than 0.5 of one Rockwell number.

Correction curves are presented, by the use of which one can obtain the true Rockwell hardness, on the "B," "F," and "G" scales, from measurements made on cylindrical surfaces.

The Rockwell method of indentation hardness testing has enjoyed wide use in this country for inspection and specification purposes, largely because of its convenience and precision. In view of the extensive use and popularity of this test, it is worth while at every opportunity to extend its applicability and to place the interpretation of its results on a more firm fundamental basis.

An attempt to extend the field of application in one particular has been made, and is described herein. This particular is the application of the Rockwell hardness test to cylindrical specimens. Heretofore, so far as the author is aware, no attempt to determine the minimum radius of curvature of specimen on which Rockwell tests may be made without appreciable error, has been reported. Neither has any determination of the error involved in making Rockwell tests on small cylindrical specimens been presented.

The purpose of this paper is to present a theoretical development and experimental confirmation of corrections to be applied to Rockwell tests made using the ball penetrators, on cylindrical specimens ranging in diameter from two to sixteen times the penetrator diammeter.

Theoretical Development:

In developing the theoretical correction, one fundamental assumption was made. This was that materials may be said to have the same indentation hardness when, using the same penetrator and the same load, the load supported per unit area perpendicular to the line of load application is the same when equilibrium is reached. This is in accordance with Meyer's definition of hardness,[2] and seemed more fundamental than Brinell's rather artificial use of spherical area of contact.

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[1] Member of Technical Staff, Bell Telephone Laboratories, New York City.

The plan of attack in developing the correction factor is to calculate the area of contact perpendicular to the line of load application, between a cylinder and a sphere, where the cylinder deforms and the sphere does not. This area we may call the normal area of contact. The normal area is calculated for various depths of penetration and cylinder radii. These areas are then equated to circular areas, and the equivalent penetration required to produce the same normal area of contact between a rigid sphere and a deformable flat surface is calculated. The assumed penetration into the cylinder and the equivalent penetration into a flat specimen are then converted into Rockwell numbers by the relation[3]

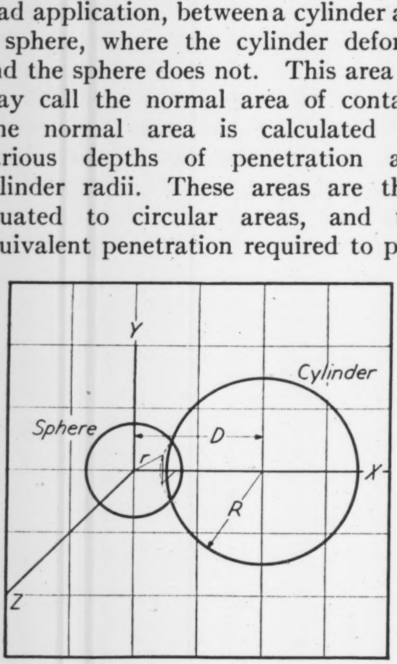

FIG. 1.—Coordinate System for Determining Contour of Intersection of Cylinder andSphere.

$$R_n = 130 - 500P \quad\text{........(1)}$$

where R_n = the Rockwell hardness number using the red figures, and

P = the penetration in millimeters.

The difference between these two values of R_n becomes a correction to be applied to the results of tests on cylindrical specimens to obtain the true hardness.

The coordinate system for calculating the area of contact is shown in Fig. 1. The origin of the cartesian system is taken at the center of the sphere.

Let r = sphere radius,

R = cylinder radius,

P = penetration of sphere into cylinder, and

D = distance between centers = $R + r - P$.

If the cylinder is displaced along the X axis, and its axis is coincident with the Z direction, the equation of the cylinder is

$$Y^2 + (X - D)^2 = R^2 \quad\text{......(2)}$$

The equation of the sphere is

$$X^2 + Y^2 + Z^2 = r^2 \quad\text{......(3)}$$

If we eliminate X between Eqs. 2 and 3, the result will be the equation of the projection of the periphery of the contact area on the Y-Z plane, which is the above defined normal area. Rewriting Eq. 2, we have

$$(X - D)^2 = R^2 - Y^2 \quad\text{.......(2a)}$$

or

$$(X - D) = \pm \sqrt{R^2 - Y^2} \quad\text{...(2b)}$$

then

$$X = \pm \sqrt{R^2 - Y^2} + D \quad\text{....(4)}$$

and

$$X^2 = R^2 - Y^2 \pm 2D \sqrt{R^2 - Y^2} + D^2 \quad\text{......(5)}$$

Substituting in Eq. 3

$$R^2 - Y^2 \pm 2D \sqrt{R^2 - Y^2} + D^2 + Y^2 + Z^2 = r^2 \quad\text{......(6)}$$

or

$$Z^2 = r^2 - R^2 - D^2 \pm 2D \sqrt{R^2 - Y^2} \quad\text{.........(7)}$$

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[2] Hugh O'Neill, "The Hardness of Metals and Its Measurement," p. 44, Chapman & Hall, London (1934).

[3] Direction Book for Rockwell Hardness Tester, Wilson Mechanical Instrument Co., WM-9.ld.

The + sign applies, since the negative value leads to imaginary roots.

While Eq. 7 is not readily recognizable as any familiar contour, when plotted it so closely resembles an ellipse for all values of the parameters in which we shall be interested, that it may be so considered for subsequent calculations. Figure 2 is a comparison of a representative curve plotted from Eq. 7 and an ellipse with the same major and minor axes. It is apparent that in considering these areas equal, little error is involved. The maximum error involved in this approximation is 0.6 per cent in area, representing 0.7 Rockwell number. This maximum occurs in the case of the smallest specimen and deepest penetration, where for other reasons the correction factor cannot be applied with confidence. The error varies roughly directly as the depth of penetration and inversely as the square of the specimen diameter.

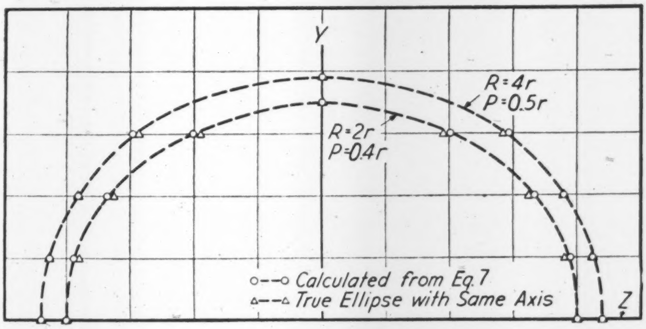

FIG. 2.—Comparison of Projection of Intersection of Sphere and Cylinder with Ellipse.

Assuming the normal area to be elliptical, it is necessary to determine the major and minor axes for each value of P, compute the area ($\pi\ a\ b$), equate it to a circular area, and solve for P', the penetration into a plane surface necessary to produce the same normal contact area.

The major and minor axes a and b may be determined by solving Eq. 7 for the conditions $y = 0$ and $z = 0$, respectively.

When $y = 0$, Eq. 7 becomes

$$Z^2 = r^2 - R^2 - D^2 + 2DR \ldots (8)$$
$$= r^2 - (R - D)^2$$

Now since

$$D = R + r - P \ldots\ldots\ldots (9)$$

$$R - D = P - r \ldots\ldots\ldots (10)$$

then

$$Z^2 = r^2 - (P^2 - 2Pr + r^2) = 2\,Pr - P^2 \ldots\ldots\ldots\ldots (11)$$

so

$$a = \pm\sqrt{2Pr - P^2} \ldots\ldots (12)$$

To determine the minor axis, set $z = 0$ in Eq. 7

$$2D\sqrt{R^2 - Y^2} = D^2 + R^2 - r^2 \ldots\ldots\ldots\ldots (13)$$

let

$$D^2 + R^2 - r^2 = M^2$$

then

$$4\,D^2\,(R^2 - Y^2) = M^4 \ldots\ldots (14)$$

or

$$y = \pm\sqrt{R^2 - \frac{M^4}{4D^2}} \ldots\ldots (15)$$

Now $M^4 = D^4 + 2D^2(R^2 - r^2) + (R^2 - r^2)^2$

$$b = \pm \sqrt{\frac{R^2 + r^2}{2} - \frac{D^2}{4}\left(1 + \frac{(R^2 - r^2)^2}{D^4}\right)}. \quad (16)$$

For a particular size sphere and cylinder, we may by use of Eqs. 12 and 16, calculate the major and minor axes of the normal contact ellipse for various depths of penetration.

This area is

$$A_N = \pi ab \ldots\ldots\ldots\ldots (17)$$

Now if the sphere had penetrated a plane surface until the load was supported by the same normal area, this area would be

TABLE I.—THEORETICAL ROCKWELL HARDNESS CORRECTION.

All loads: 1/16-in. penetrator—1/8-in. specimen—red figures.

R_n	P	a	b	c^2	P'	R'_n
130	0	0	0	0	0	130.0
120	0.02	0.17706	0.14501	0.025675	0.01634	121.8
110	0.04	0.24880	0.20445	0.050867	0.03272	113.6
100	0.06	0.30274	0.24960	0.075563	0.04912	105.4
90	0.08	0.34727	0.28724	0.099751	0.06554	97.2
80	0.10	0.38568	0.32007	0.12344	0.08199	89.0
70	0.12	0.41964	0.34945	0.14664	0.09848	80.8
60	0.14	0.45016	0.3762	0.1693	0.1150	72.5
50	0.16	0.47791	0.4008	0.1915	0.1315	64.2
40	0.18	0.50334	0.4236	0.2132	0.1481	56.0
30	0.20	0.52678	0.4449	0.2344	0.1647	47.7
20	0.22	0.54850	0.4649	0.2550	0.1813	39.4
10	0.24	0.56868	0.4838	0.2751	0.1980	31.0
0	0.26	0.58750	0.5017	0.2947	0.2146	22.7

$$A'_N = A_N = \pi c^2 \ldots\ldots (18)$$

so

$$\pi ab = \pi c^2 \text{ or } c = \sqrt{ab} \ldots (19)$$

Where c is the radius of the equivalent circle. If the sphere were penetrating a plane surface, P', the equivalent penetration can be expressed as

$$P' = r - \sqrt{r^2 - c^2} \ldots (20)$$

By Eq. 1, the equivalent, or corrected Rockwell number, R'_n is

$$R'_n = 130 - 500\,P' \ldots\ldots (21)$$

Table I presents the results of the above outlined calculation worked out in detail for the case where a $\frac{1}{16}$-in. ball penetrator is used to make tests on a $\frac{1}{8}$-in. rod.

Table II summarizes the results of the same calculation for the $\frac{1}{16}$-in. ball penetrator used on $\frac{3}{16}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$ and 1-in. rods. Here some of the intermediate steps in the calculation are omitted, but the essential figures are presented.

TABLE II.—THEORETICAL ROCKWELL HARDNESS CORRECTION FOR MEASUREMENTS MADE ON CYLINDRICAL SPECIMENS.

All loads—1/16-in. penetrator—red figures.

		3/16-in. Specimen		1/4-in. Specimen		3/8-in. Specimen		1/2-in. Specimen		3/4-in. Specimen		1-in. Specimen	
R_n	P	P'	R'_n	P'	R'_n	P'	R'_n	P'	R'_n	P'	R'_n	P'	R'_n
130	0	0	130.0	0	130.0	0	130.0	0	130.0	0	130.0	0	130.0
120	0.02	0.01734	121.3	0.01790	121.0	0.01853	120.7	0.01887	120.6	0.01922	120.4	0.01941	120.3
110	0.04	0.03471	112.6	0.03584	112.1	0.03709	111.5	0.03776	111.1	0.03846	110.8	0.03883	110.6
100	0.06	0.05211	103.9	0.05380	103.1	0.05567	102.2	0.05667	101.7	0.05772	101.1	0.05827	100.9
90	0.08	0.06955	95.2	0.07181	94.1	0.07428	92.9	0.07561	92.2	0.07699	91.5	0.07772	91.1
80	0.10	0.08701	86.5	0.08984	85.1	0.09291	83.5	0.09456	82.7	0.09629	81.8	0.09718	81.4
70	0.12	0.10452	77.7	0.10790	76.0	0.11158	74.2	0.11354	73.2	0.11559	72.2	0.11666	71.7
60	0.14	0.12206	69.0	0.12600	67.0	0.13027	64.9	0.13255	63.7	0.13492	62.5	0.13615	61.9
50	0.16	0.13964	60.2	0.14413	57.9	0.14899	55.5	0.15157	54.2	0.15427	52.9	0.15565	52.2
40	0.18	0.15724	51.4	0.16230	48.8	0.16774	46.1	0.17062	44.7	0.17362	43.2	0.17517	42.4
30	0.20	0.17489	42.6	0.18050	39.8	0.18652	36.7	0.18970	35.2	0.19300	33.5	0.19470	32.6
20	0.22	0.19257	33.7	0.19873	30.6	0.20532	27.3	0.20880	25.6	0.21239	23.8	0.21424	22.9
10	0.24	0.21029	24.9	0.21700	21.5	0.22415	17.9	0.22792	16.0	0.23180	14.1	0.23380	13.1
0	0.26	0.22804	16.0	0.23531	12.4	0.24302	8.5	0.24706	6.5	0.25123	4.4	0.25337	3.2

Experimental Confirmation:

The above-described theory was developed on the basis of an assumption which seemed reasonable, but which was not entirely established. Furthermore, no account has been taken of the lack of sphericity of the recovered impression, nor of the "piling up" of material around the impression. The theory therefore is without merit unless it can be experimentally confirmed. With a view to confirming or discounting the theory, a number of tests were made.

From various size rod stock of several metals, specimens $\frac{1}{4}$ in. long were cut, and the end faces ground parallel. These specimens were then carefully annealed, so that each would have the same hardness throughout. Rockwell hardness measurements were then made, first on the flat surface, using a spot anvil, then on the curved surface, using a large Rockwell V anvil. Three different loads were used—150, 100, and 60 kg.—in order to obtain as much spread between points as possible. Since the correction is purely a geometric one, it should work equally well for all loads. The $\frac{1}{16}$-in. ball penetrator was used in all cases. Five readings on each type surface were made on each size specimen of each material.

TABLE III.—AVERAGE RESULTS OF ROCKWELL TESTS MADE ON CURVED AND FLAT SURFACES OF ROD STOCK.

Each figure is the average of 5 readings.

Material	Diameter, in.	Curved Surface[a]			Flat Surface[a]		
		F	B	G	F	B	G
Brass	⅛	95.0	62.8	2.2	100.7	76.1	38.5
Steel	⅛	111.1	94.0	71.4	114.4	102.1	86.5
Drill rod	⅛	107.7	89.6	64.0	111.9	97.0	76.5
Aluminum	⅛	85.9	44.5	....	92.2	59.0	....
Phosphor bronze	⅛	104.4	91.5	....	110.2	99.6	....
Brass	3/16	53.5	....	....	62.4	....	....
Steel	3/16	88.8	52.0	16.0	96.3	71.6	33.6
Nickel silver	3/16	73.5	37.6	....	81.3	50.3	....
Drill rod	3/16	98.4	74.4	40.6	102.6	80.1	50.7
Brass	¼	57.4	0	....	64.0	12.0	....
Steel	¼	....	79.2	65.4	....	84.4	72.6
Nickel silver	¼	73.3	30.0	....	80.5	42.1	....
Drill rod	¼	101.2	79.5	....	104.0	84.0	....
Brass	⅜	59.1	1.0	....	65.4	11.2	....
Steel	⅜	105.9	90.3	68.8	107.2	93.6	75.5
Nickel silver	⅜	89.2	56.8	5.2	93.9	64.1	14.9
Phosphor bronze	⅜	69.2	8.6	....	73.5	17.8	....
Brass	½	58.3	6.6	....	61.5	15.0	....
Steel	½	106.6	87.0	62.3	108.0	90.7	67.6
Drill rod	½	106.7	....	62.4	108.4	....	68.3
Nickel silver	½	100.1	76.3	15.0	101.0	77.8	22.6
Phosphor bronze	½	71.5	24.4	....	74.4	30.6	....
Brass	¾	73.3	27.3	....	75.0	30.8	....
Phosphor bronze	¾	101.9	78.9	47.3	102.8	80.5	50.2
Brass	1	89.1	55.3	10.0	90.5	57.7	12.5
Phosphor bronze	1	84.3	47.8	−0.3	85.4	50.2	3.3

[a] "F" Scale—60-kg. load; $\frac{1}{16}$-in. penetrator—red figures.
"B" Scale—100-kg. load; $\frac{1}{16}$-in. penetrator—red figures.
"G" Scale—150-kg. load; $\frac{1}{16}$-in. penetrator—red figures.

NOTE.—Specimens $\frac{1}{4}$ in. long were cut from rod stock and end surfaces ground parallel. They were then carefully annealed. Measurements on flat surface were made on end of specimen using spot anvil. Measurements on curved surface were made on side of specimen, using V anvil.

The average results of these measurements are presented in Table III. Here the materials, sizes of the specimens, and average readings on all three scales on each type surface are given.

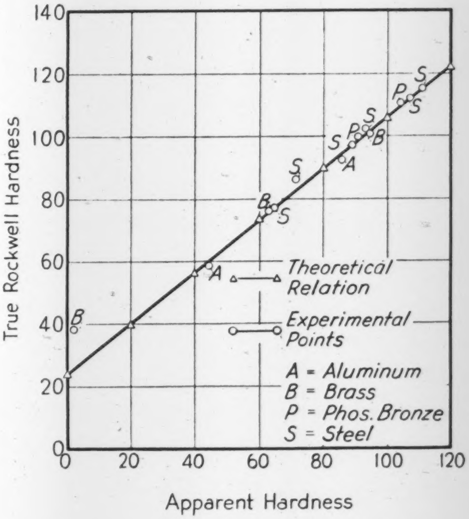

FIG. 3.—Relation Between Apparent and True Rockwell Hardness.

$\frac{1}{16}$-in. ball penetrator. $\frac{1}{8}$-in. rod specimen.

Figures 3 to 9 present graphically the relation between the apparent Rockwell hardness as measured with a $\frac{1}{16}$-in. ball penetrator on the cylindrical surface of $\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$ and 1-in. rod, and the true Rockwell hardness which would be measured on a flat surface of the same material. The curves are drawn using the calculated values, while experimental points are indicated on each figure. The material of the specimen used to obtain each point is also indicated. In view of the almost exact linearity of this relation, it will be noted that the effect of the minor load cancels out, and hence need not be calculated.

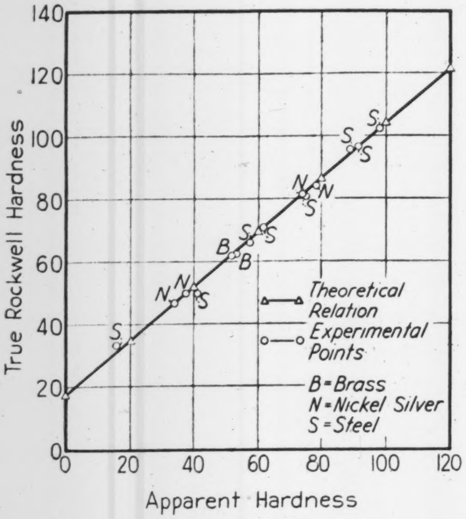

FIG. 4.—Relation Between Apparent and True Rockwell Hardness.

1/16-in. ball penetrator. 3/16-in. rod specimen.

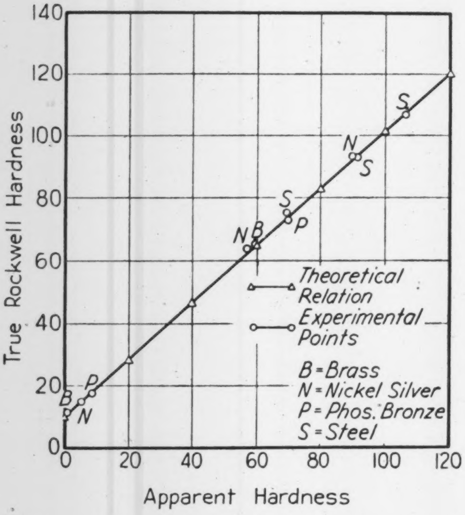

FIG. 6.—Relation Between Apparent and True Rockwell Hardness.

1/16-in. ball penetrator. 3/8-in. rod specimen.

Conclusions:

Examination of these figures will bring out several interesting and useful conclusions. The agreement between theory and experiment is entirely satis-

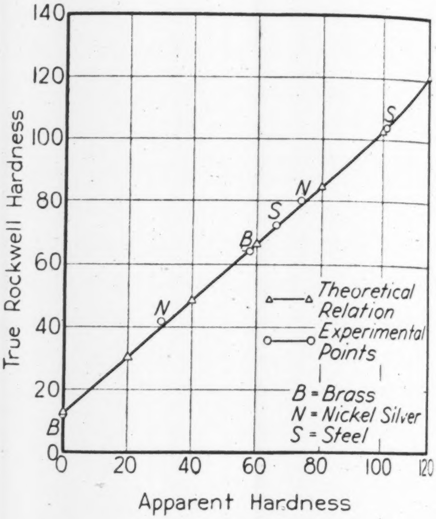

FIG. 5.—Relation Between Apparent and True Rockwell Hardness.

1/16-in. ball penetrator. 1/4-in. rod specimen.

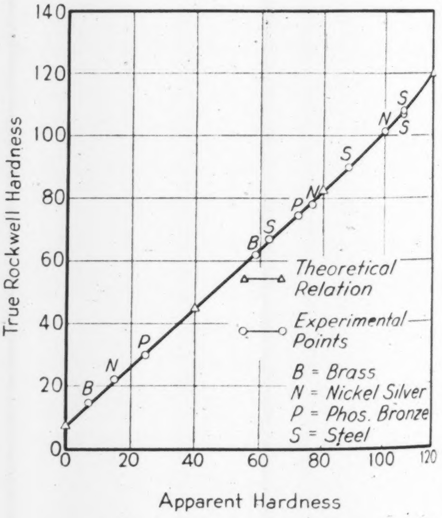

FIG. 7.—Relation Between Apparent and True Rockwell Hardness.

1/16-in. ball penetrator. 1/2-in. rod specimen.

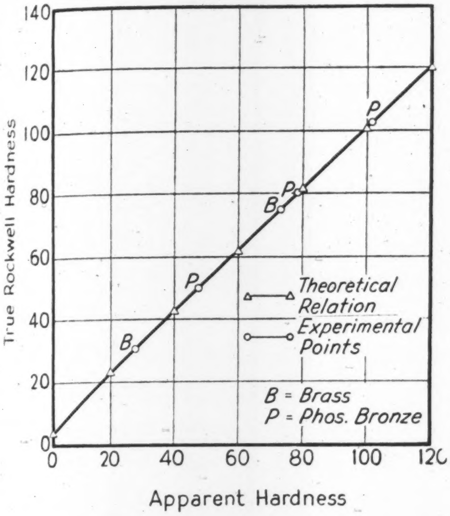

FIG. 8.—Relation Between Apparent and True Rockwell Hardness.

1/16-in. ball penetrator. 3/4-in. rod specimen.

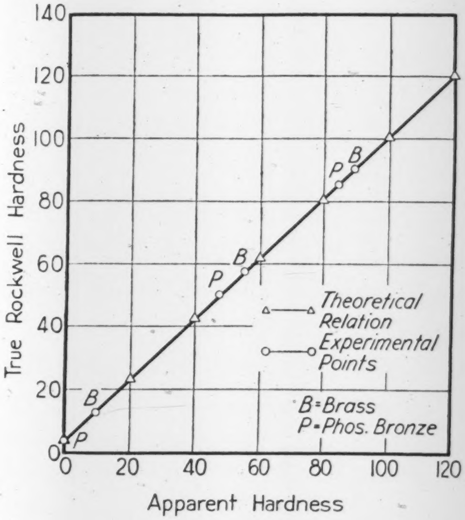

FIG. 9.—Relation Between Apparent and True Rockwell Hardness.

1/16-in. ball penetrator. 1-in. rod specimen.

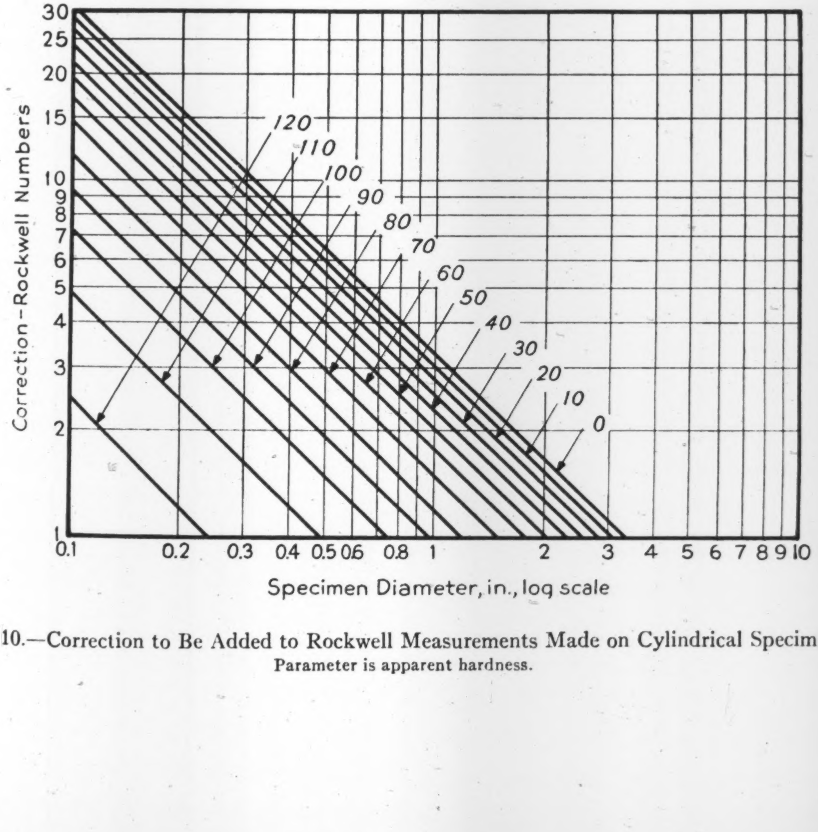

FIG. 10.—Correction to Be Added to Rockwell Measurements Made on Cylindrical Specimens.

Parameter is apparent hardness.

factory. With very few exceptions, the predicted correction differs from that measured by not more than one Rockwell number, the average spread being less than one number. The discrepancies are greatest at the lower end of the scale, particularly on the small specimens. This lack of agreement is probably due to difficulty of aligning the small rods so that the indentation will be accurately centered and, to a lesser extent, to the difference in the degree of cold working of the material under the center of the impression. Obviously this material receives more severe cold working when measurement is made on the curved surface.

The second important conclusion is that the correction is independent of the material and of the load used. This is to be expected, since no cross-comparisons are made. That is, no measurement made on one material is compared with that made on another, and no comparison is made between measurements made with different loads. The only factors that might contribute to discrepancies between measurements made on various materials is the difference in cold working characteristics and in the tendency of the material to "pile up" around the impression. These apparently are not serious.

As to the minimum diameter specimen on which measurements may be made without necessity for correction, this depends upon the hardness of the material and the degree of precision required. For instance, if a precision of one hardness number is required, measurement may be made on a 1-in. specimen if the hardness is above 80. If no correction is made, it is advisable, in order to reduce error, to use the lightest feasible load.

In Fig. 10 the correction to be added to the measurement made on the curved surface is plotted against diameter of specimen for various values of apparent hardness. By means of these curves and interpolation between them, one may readily obtain the correction to be applied to any apparent hardness value obtained on any diameter cylinder. Although experimental determinations have not been made on specimens larger than 1 in., there is reason to believe that extrapolation by means of these straight lines is possible.

The correction herein described may be used only in connection with measurements made using the $\frac{1}{16}$-in. ball penetrator. Because of geometric symmetry and the linearity of the relation as shown by Figs. 3 to 9, inclusive, it should be possible to apply the same correction to measurements made with other penetrators, the correction being the same when the penetrator to specimen diameter ratio is the same. There is no reason to anticipate difficulty in using this analogy, but no experimental tests have been made as yet to confirm this relation.

It is impossible to say at this time whether or not a relation may be established between the corrected Rockwell hardness and tensile strength. At any rate, one step has been made, by eliminating the uncertainty due to the geometry of the surface of the rod specimen.

Acknowledgments:

The author is indebted to I. V. Williams and J. P. Guerard for instruction in the principles of the Rockwell test, and to C. H. Greenall for valuable counsel. Many helpful suggestions and criticisms have also been received from J. R. Townsend, in whose department this work was conducted.

DISCUSSION

Mr. V. E. Lysaght[1] (*presented in written form*).—This paper is of real interest, especially to those who find it advisable to correlate the Rockwell numbers with tensile strength or some other property of a metal and who desire this correlation to be independent of diameter of specimen.

For control and specification purposes, however, if one will note and specify the diameter of the specimen together with the information as to whether the test was made on the cylindrical surface or on a flat spot prepared on the cylindrical surface, this information will suffice for duplication of results and generally this is all that is necessary—to be able to duplicate values permanently.

It is pointed out in the conclusion of this paper that when small rounds are to be tested, if no correction is to be made, the error due to curvature of specimen can be reduced by using the lightest feasible load. By means of the Rockwell Superficial Tester with loads of 15 or 30 kg. it is possible to test very small rounds without any appreciable error.

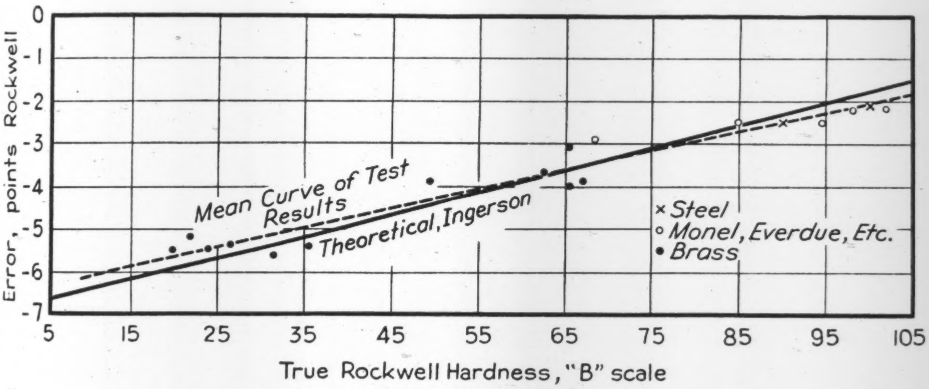

Fig. 1.—Error Due to Curvature *versus* Rockwell "B" Hardness for ½-in. Diameter Cylinders.

At the laboratories of the Wilson Mechanical Instrument Co., Inc., work has been completed by actual tests in order to determine the error due to radius of curvature. The agreement between the theoretical results of Mr. Ingerson, as described in this paper, and the tests made by the Wilson Mechanical Instrument Co. are shown in the accompanying Fig. 1. The values for ½-in. diameter cylinders are shown, but tests completed on other diameter work show equally good agreement.

These results shown in the curve were obtained on ½-in. diameter cylinders,

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[1] Engineer, Wilson Mechanical Instrument Co., Inc., New York City.

1 in. in length. Each cylinder had a flat about $\frac{3}{16}$ in. long running the full length of the specimen. Tests were made on both the flat and the cylindrical surfaces. Thirty-six specimens of both ferrous and non-ferrous materials of different hardnesses were tested. It will be noted from this curve that the results obtained on the actual tests are in very close agreement with the theoretical values determined by the method proposed in this paper.

MR. H. S. FREYNIK[2] (*presented in written form*).—The extension of the Rockwell hardness test to cylindrical specimens is, of course, a matter of considerable practical importance. There is a considerable demand for a simple method of test which will afford a more definite determination of the properties of round wire or rods. The effort made in placing interpretation of the results on a more firm fundamental basis is commendable.

Our comments on this paper resolve themselves in the statement made in the second paragraph under "Experimental Confirmation," namely, "These specimens were then carefully annealed, so that each would have the same hardness throughout." We wonder whether any attempt was made to determine whether there is agreement between theory and experiment in testing cylindrical specimens of the various metals in the cold-worked condition, as received from the manufacturer. We do not believe that this agreement will be obtained because the hardness throughout the cross-section of hard-rolled rods is not the same, especially in rods of larger diameters. Much rod is finished by cold rolling as well as drawing; therefore, higher values are obtained near the surface of the rod as compared to the section near the center. In addition, some rods are occasionally finished which are square, or some shape other than round, at the last anneal, and as a consequence some variation in Rockwell hardness values would be obtained around the surface as well as variation from center to edge of rod. Under these conditions, the tensile strength method has been the only method of testing accepted heretofore.

We realize that no relationship has been established by the authors between the corrected Rockwell hardness and tensile strength of cylindrical specimens. Under the circumstances just mentioned, we cannot see how the interpretation of the Rockwell hardness results can be placed on a firmer fundamental basis, or a corresponding relationship obtained with tensile strength, except when the hardness is uniform throughout the cross-section.

MR. W. E. INGERSON[3] (*author's closure*).—While it is true, as Mr. Lysaght points out, that for control and specification purposes reproducibility of results will suffice, it seems to me that the specification of hardness limits for rod stock which are independent of specimen diameter will be much simpler, inasmuch as there will be only one set of specification limits rather than separate ones for each size rod covered by the specification.

The advantages to be gained by using light loads are not so great as they seem at first glance. While the actual error in hardness numbers is small for the smaller penetrations, due to the decreased sensitivity of the scales at the upper end, when conversion is made (by means of empirically established equivalent values) the equivalent error on the more sensitive scales is almost as great as the error involved had the measurement been made using the more sensitive scale. For example, suppose a measurement is made, using the 30-T scale on a ½-in. specimen, and the hardness is 40. For this value on the superficial machine P is 0.001 (100 − 40) = 0.06. Referring to Table II, P' is 0.05667. The true superficial hardness is therefore 100 − 56.7 = 43.3. The equivalent values on the B scale (from the empirical conversion tables) are $R_n = 36$ and $R'_n = 40.6$. Therefore, the equivalent error on the B scale is 4.6 numbers. If measurement had been made on the B scale directly, reference to Fig. 10 indicates that the correction corresponding to a ½-in. specimen of hardness 36 would be about 4.7. It therefore appears that little is to be gained by using the superficial machine to eliminate the effect of curvature.

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[2] Metallurgist, The Riverside Metal Co., Riverside, N. J.

[3] Member of Technical Staff, Bell Telephone Laboratories, New York City.

It is gratifying to know that the experimental results obtained independently in the laboratories of the Wilson Mechanical Instrument Co. check so closely with both the theoretical and experimental values presented in the paper. My thanks are due to Mr. Lysaght for the presentation of these corroborative data.

It is true, as Mr. Freynik points out, that the hardness of cold-rolled or drawn rod is not uniform throughout. This, however is not necessarily an insurmountable obstacle in the correlation of hardness with, say, tensile strength. Such correlation is satisfactorily obtained for thick sheet material, where the hardness (and related tensile strength) vary with depth from the surface. A mathematical formulation for the relation between Rockwell hardness and tensile strength is presented by Peek and Ingerson,[4] wherein this variation of tensile strength of individual fibers with depth is included by assuming that

$$S = S_0\left(\frac{h}{D}\right)^K$$

where:

S = the tensile strength of the individual fiber,

S_0 = the average tensile strength throughout the specimen,

D = the diameter of the penetrator,

h = the depth from the surface, and

K = a constant determined empirically.

The relation is, of course, only approximate, but nevertheless provides satisfactory agreement for thick sheet specimens. There is reason to believe that it should also work in the case of the rod specimens, once the effect of curvature proper has been eliminated by the method outlined in this paper.

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[4] See p. 1270.

A STUDY OF THE INFLUENCE OF SPEED ON THE TORSION IMPACT TEST

By O. V. Greene[1] and R. D. Stout[1]

Synopsis

This paper describes further experiments on the effect of velocity in torsion impact testing of hardened 1.10 per cent carbon tool steel. A range of speeds is investigated on the torsion impact machine and on a static torsion machine.

As a part of the necessary information in the use of the static test, the modulus of torsion of hardened and drawn 1.10 per cent carbon tool steel has been determined.

Data are presented to show that torsion impact values are constant at the speeds investigated; and that both impact and static tests show the same shape of curve when breaking energies are plotted against drawing temperature. An explanation is offered for the disparity between fast and slow tests at drawing temperatures below 400 F.

The results indicate that the torsion impact test is essentially a rapid static test.

The development and significance of the torsion impact test on hard, low ductility materials have been described in previous papers.[2, 3, 4] Naturally in the development of a new type of impact test designed to test a class of materials previously unevaluated, it is to be expected that numerous problems will suggest themselves. In impact testing the question of speed is of importance.[5, 6] In a paper by one of the authors in 1933[2] a very limited number of experiments on the effect of velocity of the flywheel is included. The present paper is intended to report a more complete survey of the effect of speed on torsion impact values of straight carbon tool steel.

In order to investigate speed, it is essential to preserve an energy level in the rotor of the impact machine well above that necessary to break the specimen. It is evident that as the velocity is lowered, the moment of inertia of the rotor must be raised to impracticable values to accomplish this. Consequently, in approaching zero velocity, it is convenient to resort to a form of static torsion test in which work values can be obtained.

Test Procedure:

Three ranges of speed were chosen for this investigation.

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[1] Metallurgical Dept., The Carpenter Steel Co., Reading, Pa.

[2] G. V. Luerssen and O. V. Greene, "The Torsion Impact Test," *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 315 (1933).

[3] G. V. Luerssen and O. V. Greene, "The Torsion Impact Properties of Tool Steel," *Transactions*, Am. Soc. Metals, Vol. 22, p. 311 (1934).

[4] G. V. Luerssen and O. V. Greene, "Interpretation of Torsion Impact Properties of Carbon Tool Steel," *Transactions*, Am. Soc. Metals, Vol. 23, p. 861 (1935).

[5] H. C. Mann, "High-Velocity Tension-Impact Tests," *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part II, p. 85 (1936).

[6] Symposium on Impact Testing, *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 21 (1938).

1. *High-Velocity Test.*—This is the standard adopted for the torsion impact test and was obtained from the type of machine shown in Fig. 1. A velocity of 700 r.p.m. was used, equivalent to an angular velocity of 73 radians per second.

2. *Low-Velocity Test.*—The original machine described in the 1933 paper[2] was used, but converted by a special high-torsion flywheel to possess the same energy at 100 r.p.m. as that developed in the standard machine at 700 r.p.m. The angular velocity of 100 r.p.m. is 10.5 radians per second.

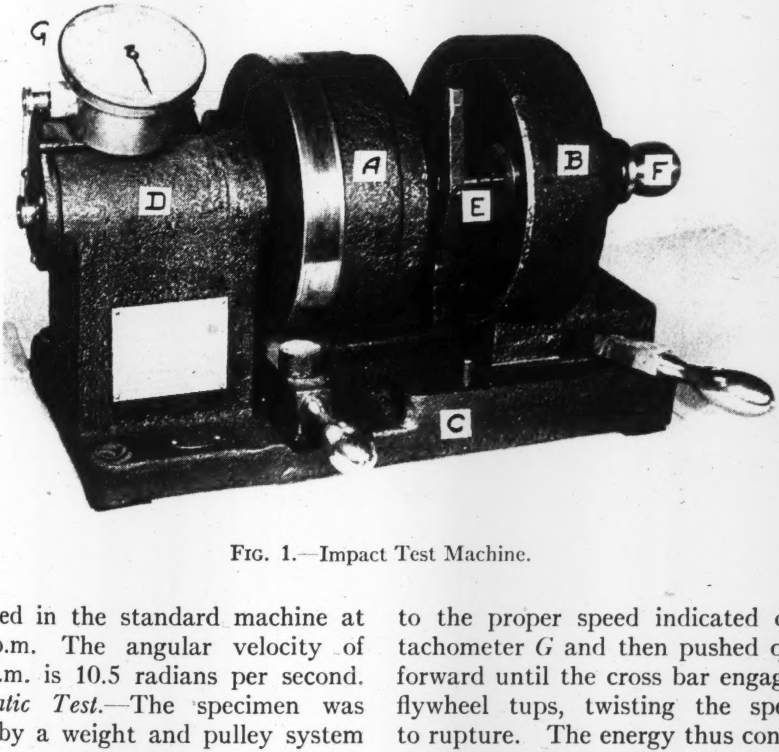

FIG. 1.—Impact Test Machine.

3. *Static Test.*—The specimen was loaded by a weight and pulley system whereby actual torque and deflection readings were obtained. The time of test was 15 sec. to 10 min., or 0.1 to 0.001 radians per second.

In the earlier paper[2] the original torsion impact machine is described in detail. The present machine shown in Fig. 1 is essentially the same as the original except for slight improvements. The machine consists of a rotor *A* and a fixed head *B*, both rigidly fastened to a bed plate *C*. The rotor consists of a flywheel on a shaft rotating freely in a ball bearing mounted in housing *D*. The flywheel carries on its outer face two tups not visible in the photograph. The specimen *E* with its cross bar is gripped in a sliding chuck *F*, which is pulled back while the rotor is brought to the proper speed indicated on the tachometer *G* and then pushed quickly forward until the cross bar engages the flywheel tups, twisting the specimen to rupture. The energy thus consumed is indicated by the drop in velocity of the rotor. At 700 r.p.m. (73 radians per second), the kinetic energy of the rotor is 250 ft-lb.

For the tests at 100 r.p.m., a machine is used with a double flywheel to which are added ten lead spokes weighing 25 lb. each. The energy in this flywheel at 100 r.p.m. (10.5 radians per second) is 249 ft-lb.

Figure 2 represents the arrangement for static tests. Following the experiments at 100 r.p.m., the lead spokes were removed, and in their stead was mounted a 48-in. diameter wheel, *A*, on the periphery of which was fastened a cord and bucket, *B*, whereby the torque was applied, using sand for the loading agent. This adaptation is similar to that used in tests reported by Sauveur.[7] The torsion specimen *C* is gripped at its ends by a fixed chuck, *D*, and the rotating chuck *E* connected to the torque wheel. A deflection scale *F* is fastened near one end of the specimen, and a pointer *G* near the other. In connection with the measurement of deformation, it was necessary to make modulus determinations of a uniform section, and by a method shown later to correct for the elastic twist of the specimen sections separating the actual gage length from the measuring device. In order to avoid bending moment, the specimens were checked closely for concentricity, and care was observed in mounting the specimens in the grips.

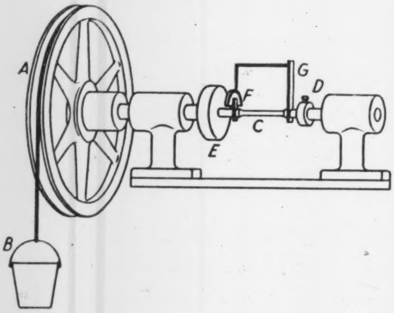

FIG. 2.—Static Test Machine.

A heat of carbon tool steel of the following analysis was used throughout the investigation:

Carbon, per cent	1.10
Manganese, per cent	0.25
Silicon, per cent	0.27
Phosphorus, per cent	0.018
Sulfur, per cent	0.016

The specimens were hardened by heating for 3 min. in a lead bath at 1450 F., followed by brine quenching, and drawing at various temperatures.

The dimensions of the standard torsion impact specimen used for both impact and static tests are shown in Fig. 3. This round-end type has been adopted in place of the square end for its greater ease of preparation, its lessened tendency to warp in hardening, and better seating in the chucks in testing.

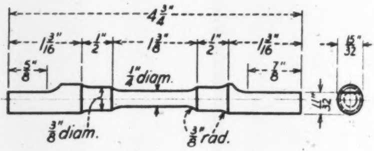

FIG. 3.—Torsion Impact Test Specimen.

Test Data:

The static torsion test was conducted by applying definite increments of load to the specimen and reading the angular deformation accompanying them, continuing to the point of failure. From the load acting on the circumference of the torque wheel, the torque in pound-inches was calculated. The torque and deformation data were then used to plot a torque-strain curve from which an evaluation of work in foot-pounds was obtained. Before this could be done, however, it was necessary to refer the deformation data obtained from the clinometer to the 1-in. gage length, which involved correction for the elastic twist of the fillets and larger sections of the shanks. The mode of correction involves the use of the modulus of torsion, which is an important constant in torsion formulas applicable to stresses under the elastic limit. Since published values of the modulus are somewhat at variance, this constant was determined by what is known as the direct method, in which special specimens of uniform section, $\frac{1}{2}$ in. round, brine quenched at 1450 F., and drawn at 350 to 800 F., were used. A special clinometer was fastened to the section to obtain measurements of deformation, accurate to 0.0003 radians. This permitted the use of a series of low loads well below the elastic limit. The torsion formula for a circular cross-section is

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[7] Albert Sauveur, "The Torsion Test" (Edgar Marburg Lecture), *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 3 (1938).

$$F = \frac{10.18TL}{\phi d^4} \quad \ldots\ldots\ldots (1)$$

where F = the torsion modulus,
T = the torque in pound-inches,
L = the gage length in inches,
ϕ = the deformation in radians, and
d = the diameter in inches.

Using this formula, a consistent value of modulus was found over the drawing range, the average value for F being 10,800,000 psi. This is in good agreement with values obtained by Zimmerli, Wood and Wilson[8] and Ludewig.[9]

The standard impact specimen was substituted in the arrangement used for the modulus determination, and torque-deformation data carefully determined. It can be seen from Eq. 1 that

$$\phi = \frac{10.18TL}{Fd^4} \quad \ldots\ldots\ldots (2)$$

From Eq. 2, the expected deformation of the 1-in. gage length can be calculated for the torque values used in the experiment above. The actual clinometer readings in this test exceed the theoretical values in a definite ratio. The difference between these observed values

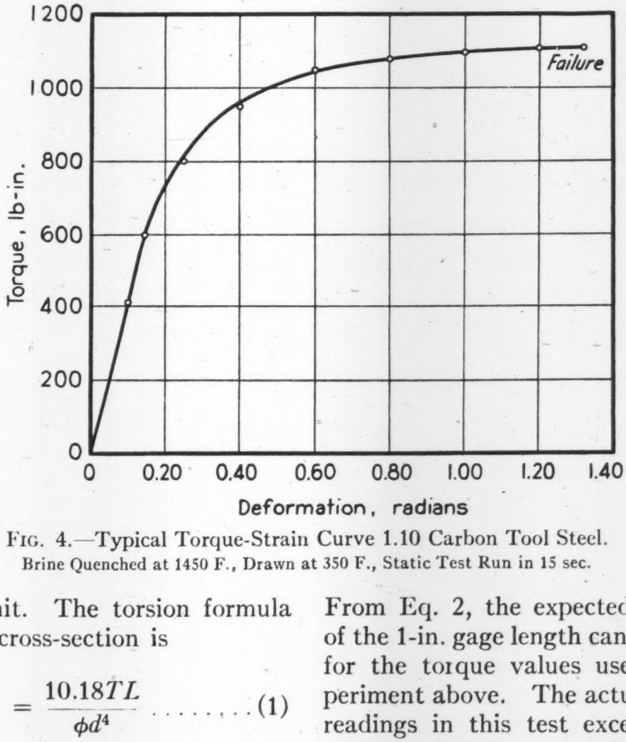

FIG. 4.—Typical Torque-Strain Curve 1.10 Carbon Tool Steel.
Brine Quenched at 1450 F., Drawn at 350 F., Static Test Run in 15 sec.

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[8] F. P. Zimmerli, W. P. Wood and G. D. Wilson, "The Effect of Temperature upon the Torsional Modulus of Spring Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 30, Part II, p. 350 (1930).

[9] J. W. Ludewig, "Torsional Moduli Variations of Spring Materials with Temperature," *Transactions*, Am. Soc. Metals, Vol. 22, p. 833 (1934).

and the theoretical represents the elastic deformation of the fillets and shanks of the specimens. This correction was then applied to the deformation values in the static test.

A typical torque-strain curve is shown in Fig. 4. The area under the curve represents work in inch-pounds and can be measured by a planimeter or by a count of unit squares.

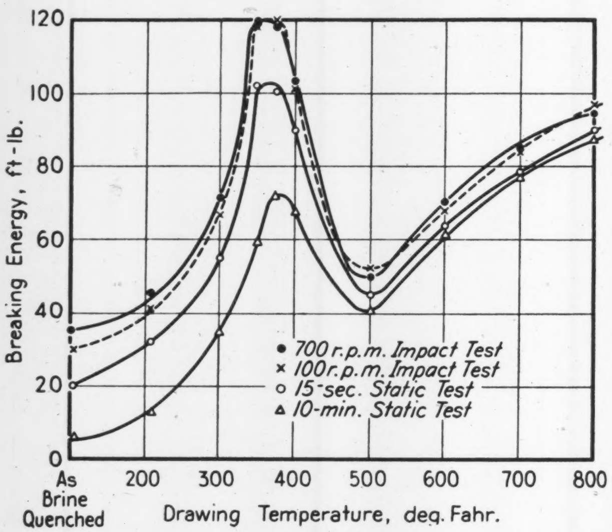

FIG. 5.—Effect of Drawing Temperature on Torsion Values of 1.10 Carbon Tool Steel Tested at Various Speeds.

Hardened by Brine Quenching at 1450 F., and Drawn as Shown.

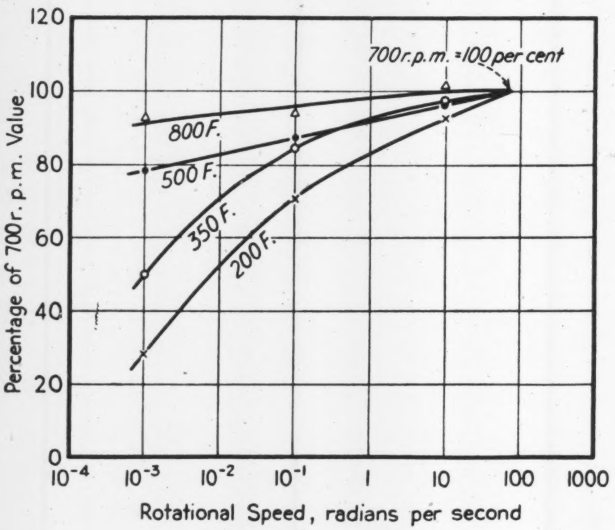

FIG. 6.—Effect of Speed on the Breaking Energy Expressed as Percentage of the Value Obtained at 700 r.p.m. for Various Drawing Temperatures.

1.10 Carbon Tool Steel, Brine Quenched at 1450 F.

The question may arise as to the elastic energy released from the specimen at the time of rupture. In the impact test, this is returned to the flywheel in varying degree, according to the locus of rupture. From the static test it has been found that the elastic energy involved is in the order of 10 ft-lb. In the integration of the torque-strain curve in the static test, one half of this energy has been included.

The data used in Figs. 5 and 6, with corresponding Rockwell hardness, "C" scale, values, are shown in Table I. All specimens were brine quenched from 1450 F., and drawn at 212 to 800 F. Figure 5 shows the relation of breaking energy to drawing temperature at various speeds. In Fig. 6 the relation of breaking energy to speed is shown in a series of curves. It is convenient to compare the speeds by using the 700 r.p.m. test as a standard and to denote the values at lower speeds as a percentage of the value obtained at this velocity.

TABLE I.—BREAKING ENERGY IN TORSION AT VARIOUS SPEEDS AND DRAWING TEMPERATURES.

1.10 per cent carbon tool steel, brine quenched 1450 F., and drawn as shown.

Drawing Temperatures, deg. Fahr.	Breaking Energy, ft-lb.				
	700 r.p.m., 73 radians per second	100 r.p.m., 10.5 radians per second	15-sec. Test, 0.1 radians per second	10-min. Test, 0.001 radians per second	Rockwell Hardness, "C" Scale
As brine quenched	35	30	20	6	66
212	45	41	32	13	66
300	70	66	54	34	65
350	120	120	102	60	63 to 64
375	118	119	100	72	62 to 63
400	105	102	90	68	61 to 62
500	50	52	45	41	58 to 59
600	70	68	64	61	54
700	85	84	78	77	50 to 51
800	95	98	90	88	47

Discussion of Results:

In Fig. 5 the curve of data obtained on the impact machine at 700 r.p.m. (73 radians per second) is a typical torsion impact curve of 1.10 per cent carbon tool steel as shown in previous papers.[3, 4] It is of interest to note that the curve at 100 r.p.m. (10.5 radians per second) has the same magnitude and form as that obtained at the higher velocity. It appears, in confirmation of the limited evidence in the first paper,[2] that the torsion impact values will be consistent over the full range of speed available from the standard machine. The values obtained by the 15-sec. static test (0.1 radians per second) fall along a curve similar in form, but with a magnitude somewhat lower at temperatures below 400 F. With a drawing temperature above this range, the static tests agree more closely with impact values. The curve representing the 10-min. static test (0.001 radians per second) shows, below 400 F., an even greater displacement from the impact figures, although of the same form. At the higher drawing temperatures, this curve also closely approaches the others. The effect of speed over the drawing range is shown in Fig. 6 somewhat more strikingly. It will be noted that at a drawing temperature of 200 F., the breaking energy of the 10-min. test is but 30 per cent of that at 700 r.p.m. At 350 F., this ratio has risen to 50 per cent, and at the highest draw, 800 F., the value is over 90 per cent of the impact figure. Furthermore, the percentage difference decreases uniformly with increase of speed of test.

The discrepancies existing between the impact tests and the static tests at low drawing temperatures is sufficiently large to warrant some explanation as to its cause. It has been shown in numerous papers[10, 11] that high internal stresses are

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[10] H. Scott, "The Origin of Quenching Cracks," *Scientific Paper No. 513*, Nat. Bureau Standards (1925).

[11] O. V. Greene, "Estimation of Internal Stress in Quenched Hollow Cylinders of Carbon Tool Steel," *Transactions*, Am. Soc. Metals, Vol. 18, p. 369 (1930).

set up in a quenched piece of steel which are not wholly relieved by tempering until temperatures of 500 F. or higher are reached. It is likewise well established that appreciable amounts of austenite are retained in hardened steel and persist at least in part up to temperatures of 400 to 450 F. Specimens, then, which have not been reheated above 400 F. are characterized by the presence of retained austenite and varying amounts of internal stresses.

Considerable evidence has been presented[4] to prove that the peak in the impact curve is due to a combination of stress relief and the cushioning effect of the retained austenite, the disappearance of which is accompanied by a sharp drop in toughness and ductility, as evinced by the deep valley in the curve at 500 F. The decomposition of austenite at room temperature is known to be affected by the presence of high pressure or stresses, and a tensile load has been demonstrated to accelerate the rate of austenitic decomposition. Mechanical work encourages atomic mobility and thus aids in the tendency to approach equilibrium, which here involves the breaking down of austenite to more stable aggregates. It is thought that at low speeds of testing, stress is applied so slowly that the conditions of metastable equilibrium are upset, and the austenite is given an opportunity to decompose and thus replace a ductile phase with one that is hard and brittle. Failures at low deformation values are the result. The mechanism of the reaction is entirely similar to the tendency of a supercooled solution to establish equilibrium conditions when the system is disturbed.

Faster testing reduces the time during which the austenite-martensite reaction can proceed automatically, and consequently the breakdown of the austenite is restricted to that caused directly by cold work. Therefore the familiar ductility of austenite is evinced and larger deformations are possible. It is further believed that in specimens in the as-quenched condition, and as drawn below 350 F., the presence of high internal stresses enhances their sensitivity to the above phenomenon. At drawing temperatures resulting in the complete decomposition of austenite, speed is found to have very little effect on torsion values.

From this study of speed, the inference may be drawn that the torsion impact test is a fast static test, which coincides with the assertions made by Mann[5] that all impact tests below a critical velocity peculiar to the material are in reality static in nature.

Summary:

1. The modulus of torsion of hardened and drawn 1.10 per cent carbon tool steel was found to be about 10,800,000 psi.
2. The torsion impact values were found to be consistent over the range of speed investigated.
3. Both impact and static tests show the same shape of curve when breaking energies are plotted against drawing temperature, but at temperatures below 400 F. values decrease as speed of test is decreased.
4. For drawing temperatures above 400 F., there is a good agreement at all velocities of testing.
5. An explanation is offered to account for the low breaking energies obtained with low testing speeds for drawing temperatures below 400 F. It is suggested that the application of stress encourages the tendency of austenite to decompose to a less ductile structure, which, however, involves a definite time factor. The extent of this action is thus dependent on the duration of test, which, if short enough, causes it to become negligible and permits the full cushioning effect of the austenite.
6. The torsion impact test can be regarded as a rapid static test.

SUMMARY OF PROCEEDINGS OF THE COLUMBUS REGIONAL MEETING

SYMPOSIUM ON LIME

SYMPOSIUM ON THERMAL INSULATING MATERIALS

The tenth regional meeting of the Society was held in Columbus, Ohio, at the Deshler-Wallick Hotel, on Wednesday, March 8, 1939, in conjunction with the Spring Group Meeting of A.S.T.M. Committees. The regional meeting consisted of two formal technical symposiums—one on Lime, and the other on Thermal Insulating Materials.

Symposium on Lime:

A morning and afternoon session of the meeting were devoted to the Symposium on Lime, sponsored by Committee C-7 on Lime. While Committee C-7 acted as a committee of the whole, six of its members were directly responsible for its development, as follows:

James R. Withrow (*Chairman*), Chairman and Professor, Department of Chemical Engineering, and Consulting Chemical Engineer, Ohio State University.

John W. Stockett, Jr. (*Secretary*), Secretary, National Lime Assn.

F. O. Anderegg, Consulting Specialist on Building Materials, Owens-Corning Fiberglas Co.

L. E. Johnson, Secretary and General Manager, The Finishing Lime Assn. of Ohio.

James O. Pence, Instructor in Chemical Engineering, Ohio State University.

J. C. Pearson, Director of Research, Lehigh Portland Cement Co. (representing Committee E-6 on Papers and Publications).

This symposium covers a number of fundamental aspects, certain research angles, and deals especially with problems in the practical application of lime in its various forms. The symposium consisted of the following twelve papers:

"Lime Investigations—an Introduction to the Symposium on Lime," by James R. Withrow.

"Variations in Properties of Dolomitic Lime Putties with Method of Hydration," by John E. Conley, Associate Chemical Engineer, U. S. Bureau of Mines.

"The Hydration of Magnesian Lime and the Autoclave Test," by F. C. Welch, Chemist, The Western Lime and Cement Co.

"Manufacturing Lime for the Glass Industry," by A. H. Nieman, Chemist, The Ohio Hydrate and Supply Co.

"Factors Affecting Milks of Lime Employed in Industry," by D. E. Washburn, Chief Chemist, American Lime and Stone Co.

"Quality of Lime Desired for Water Treatment," by Charles P. Hoover, Chief Chemist, Columbus Water Works.

"Prevention of After-Precipitation in Lime-Treated Industrial and Municipal Waters by Threshold Treatment," by Owen Rice, Research Engineer, Everett P. Partridge, Director of Research, and R. E. Hall, Director, Hall Laboratories, Inc.

"Soil Acidity and Liming, and Some Factors That Should Determine the Standards for Lime for the Soil," by Elmer O. Fippin, Agricultural Adviser, Department of Agricultural Relations, Tennessee Valley Authority.

"Criteria for the Evaluation of Agricultural Ground Limestone," by R. M. Salter, Professor of Agronomy, Ohio State University, and C. J. Schollenberger, Associate in Agronomy, Ohio Agricultural Experiment Station.

"Preliminary Investigation of the Determination of Fluorine in Lime," by C. J. Koehler, In Charge of Lime and Calcium Carbonate, Research and Quality Dept., National Gypsum Co.

"Fundamental Mechanics of Calcination and Hydration of Lime and Methods of Control," by Victor J. Azbe, Consulting Engineer, St. Louis, Mo.

"Lime Characteristics and Their Effect on Construction," by Walter C. Voss, Professor of Building Construction, Massachusetts Institute of Technology.

The chairman at the sessions was Mr. Withrow, who was assisted by Mr. Anderegg as co-chairman.

Symposium on Thermal Insulating Materials:

An afternoon session of the regional meeting comprised a Symposium on Thermal Insulating Materials, held simultaneously with the Symposium on Lime, and sponsored jointly by Committee C-16 on Thermal Insulating Materials and Committee C-8 on Refractories.

The committee immediately in charge of the program consisted of the following:

J. H. Walker (*Chairman*), Engineer Assistant to General Manager, The Detroit Edison Co.
C. B. Bradley, Research Physicist, Johns-Manville Research Laboratories.
E. T. Cope, Research Dept., The Detroit Edison Co.
R. E. Cryor, Research Engineer, Union Asbestos and Rubber Co.
H. C. Dickinson, Chief, Heat and Power Division, National Bureau of Standards.
O. E. Harder, Assistant Director, Battelle Memorial Inst.
R. H. Heilman, Senior Industrial Fellow, Mellon Institute of Industrial Research.
M. F. Skinker, Associate Director of Research, Consolidated Edison Co. of N. Y., Inc. (representing Committee E-6 on Papers and Publications).

The purpose of the symposium was to point out important problems in the field of standardization and research which will need to be considered carefully by Committee C-16, and also to present the latest thoughts and suggestions on various points. The symposium consisted of the following five papers:

"Introduction," by J. H. Walker.

"Factors Influencing the Thermal Conductivity of Non-Metallic Materials," by J. B. Austin, Research Laboratory, United States Steel Corp.

"A Discussion on Test Methods for Determining Physical Properties of Plastic and Preformed Thermal Insulations," by H. H. Rinehart, Insulation Engineer, Johns-Manville Research Laboratories.

"One Consumer's Problems in Selecting Heat Insulation," by E. T. Cope, Research Dept., and W. F. Kinney, Production Dept., The Detroit Edison Co.

"The Effect of Solar Radiation on the Heat Transmission Through Walls," F. C. Houghten, Director, Carl Gutberlet, Research Assistant, and Albert A. Rosenberg, Research Engineer, Research Laboratory, American Society of Heating and Ventilating Engineers.

The chairman of the session was Mr. Walker, who was assisted by Mr. Harder as co-chairman.

The papers in both of the above symposiums elicited a considerable amount of discussion which contributed greatly to the information contained in the papers. The papers of the two symposiums, complete with discussion, have been published by the Society as separate volumes entitled, respectively, "Symposium on Lime," and "Symposium on Thermal Insulating Materials."

The three technical sessions were very well attended, there being about 250 present at each session.

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